THE
ASTROPHYSICAL JOURNAL
AN INTERNATIONAL REVIEW OF SPECTROSCOPY
AND ASTRONOMICAL PHYSICS

VOLUME XXIX JANUARY 1909 NUMBER 1

NOTES ON THE POSSIBILITY OF FISSION OF A CONTRACTING ROTATING FLUID MASS[1]

By F. R. MOULTON

I. INTRODUCTION

In the speculations on cosmogony there are two fairly definite hypotheses as to the manner in which a single body may give rise to two or more distinct masses without the intervention of external agencies. The first, as outlined by Laplace, is that possibly a rotating fluid may abandon an equatorial ring, which will subsequently be brought by its self-gravitation into an approximately spherical mass. The second, the fission theory, had its rise in Darwin's researches on tidal evolution, and in his speculations on the origin of the moon. It has found extensive application in attempts at explaining the great abundance of binary stars.

The hypothesis of Laplace has the support of no observational evidence, unless we regard the rings of *Saturn* as such, and rests upon no well-elaborated theory. On the contrary there are well-known considerations of the moment of momentum of our system which compel us to reject it as being an unsatisfactory hypothesis for the explanation of the development of the planets. But the fission theory of Darwin, even if the origin of the moon is left aside as being doubtful, has strong claims for attention because of its immediate application to explaining the origin of spectroscopic and visual binaries and certain classes of variable stars. Besides, it is in a general way confirmed by the investigations of Maclaurin, Jacobi, Thomson,

[1] Abstract of a paper published by the Carnegie Institution.

Poincaré, and Darwin on the figures of equilibrium of rotating homogeneous fluids, and on their stabilities. In particular, considering a series of homogeneous fluid masses of the *same* density but of *different* rates of rotation, it is shown that there is a continuous series of figures of stable equilibrium beginning with the sphere for zero rate of rotation; then, with increasing rotation, passing along a line of oblate spheroids until a certain rate of rotation is reached; then, with decreasing rate of rotation but with increasing moment of momentum, branching to a series of ellipsoids with three unequal axes, and continuing until a certain elongation is reached; and finally, at this point, branching to a series of so-called pear-shaped figures. It has been conjectured that if it were possible to follow the pear-shaped figures sufficiently far, it would be found that they would eventually reach a point where they would separate into two distinct masses. From this line of reasoning it has been regarded as probable that celestial masses, through loss of heat and consequent contraction, do break up in this way often enough to make the process an important one in cosmogony.

Aside from the unanswered question as to what form the pear-shaped figures finally lead, there are two reasons for being cautious in accepting the conclusions. One is that the celestial masses are by no means homogeneous. When they have reached, or are in, that condition of steady motion of slow rotation postulated in the investigation, they are undoubtedly always strongly condensed toward their centers. The other, and probably more important, one is that isolated celestial masses do not change their rates of rotation except when they change their densities or distribution of densities. While the theoretical discussions to which reference has been made regard the rate of rotation as the single variable parameter, in the actual case there is a corresponding change in density. The importance of not neglecting the latter is easily seen.

Consider a slowly rotating homogeneous fluid having the form of a nearly spherical oblate spheroid. The eccentricity of a meridian section depends upon the quantity $\frac{\omega^2}{2\pi k^2 \sigma}$, where ω is the angular rate of rotation, k^2 the gravitational constant, and σ the density of the mass. The eccentricity of the axial section increases with the

increase of this function provided it does not go beyond a certain maximum. Now suppose the mass contracts in such a way as to remain homogeneous throughout, and so that it continues to rotate as a solid spheroid of equilibrium. Because the moment of momentum of an isolated mass is constant, the contraction implies an increase in ω, and therefore, so far as this factor alone is concerned, an increase in the oblateness of the mass. But the contraction also implies an increase in σ, and therefore, so far as this factor alone is concerned, a decrease in the oblateness of the mass. That is, keeping the moment of momentum constant, as the dynamical situation requires, we find the eccentricity acted upon by two opposing factors. If, under the influence of these factors, the figures should become less oblate, the fission theory would get no support from the discussion; if it should get more oblate, the question is at what rate the mass must rotate, and to what extent the contraction must proceed before there is a possibility of fission. This paper is devoted to a brief discussion of these questions.

II. THE ELLIPSOIDAL FIGURES OF EQUILIBRIUM OF ROTATING HOMOGENEOUS FLUIDS

For the applications which follow it will be necessary to review briefly the facts regarding the spheroidal and ellipsoidal figures of equilibrium and their conditions of stability.

Maclaurin[1] has shown that for very small values of $\frac{\omega^2}{2\pi k^2\sigma}$ there are two ellipsoids of revolution which are figures of equilibrium, one of them being nearly spherical, and the other very oblate, the limits for $\omega=0$ being respectively the sphere and infinite plane. For greater values of this quantity, the figure corresponding to the former is more oblate and that corresponding to the latter is less oblate. For $\frac{\omega^2}{2\pi k^2\sigma}=0.22467\ldots$ the two figures are identical. For $\frac{\omega^2}{2\pi k^2\sigma}>0.22467\ldots$ there is no ellipsoid of revolution which is a figure of equilibrium.

Jacobi has shown[2] that if $\frac{\omega^2}{2\pi k^2\sigma}<0.18709\ldots$ there is an

[1] *Treatise on Fluxions*, Edinburgh, 1742.

[2] Letter to French Academy, 1834.

ellipsoid of three unequal axes satisfying the conditions for equilibrium. When this quantity is very small the axis of rotation and one other are very small and nearly equal to each other, while the third is relatively very long. With greater values of this quantity the shorter axes are longer, and the longest axis is shorter. For $\frac{\omega^2}{2\pi k^2\sigma}=0.18709\ldots$ the figure becomes an ellipsoid of revolution and is identical with the more nearly spherical Maclaurin spheroid. For $\frac{\omega^2}{2\pi k^2\sigma}>0.18709\ldots$ the Jacobian ellipsoids of equilibrium do not exist.

In the case of the Maclaurin spheroids the relation between $\frac{\omega^2}{2\pi k^2\sigma}$ and the eccentricity, e, of an axial section is given by the well-known equation[1]

$$\frac{\omega^2}{2\pi k^2\sigma}=\frac{1}{\lambda^2}\left\{(3+\lambda^2)\frac{\tan^{-1}\lambda}{\lambda}-3\right\}. \qquad (1)$$

III. POINCARÉ'S THEOREMS RESPECTING FORMS OF BIFURCATION AND EXCHANGE OF STABILITIES

In a memoir[2] remarkable for its powerful methods and important results, Poincaré has proved the existence of an infinite number of other forms of equilibrium. Considering the equations for equilibrium as functions of the parameter ω, he showed that for an infinite number of values of ω other series of forms branch both from the Maclaurin spheroids and from the Jacobian ellipsoids. A form at which two series cross he called a *form of bifurcation*, and a form at which two series unite and disappear, a *limit form*. Starting with the nearly spherical oblate spheroid for small values of ω and following this series of forms for increasing ω, he found that the first form of bifurcation is that for which the Jacobian ellipsoids branch. Following along the Jacobian ellipsoids, he found that the first form of bifurcation is that for which the so-called pear-shaped figures branch.

Poincaré proved that if two real series of figures of equilibrium, A and B, cross, and if before crossing A is stable and B unstable, then

[1] Tisserand, *Mécanique céleste*, **2**, chap. vi.

[2] "Sur l'équilibre d'une masse fluide animée d'un mouvement de rotation," *Acta Mathematica*, **7**, 259–380, 1885.

after crossing A is unstable and B has at least one degree less of instability. Starting with the nearly spherical oblate spheroids, he proved that they are absolutely stable, and that they remain absolutely stable until the Jacobian ellipsoids branch. At this point they become unstable and the branching Jacobian ellipsoids are stable. These latter figures remain stable until the pear-shaped figures branch, where they lose their stability. Darwin concluded from a computation of the first terms of an infinite series[1] that the pear-shaped figure is stable. On the other hand Liapounoff asserts[2] it is unstable. If it is stable, apparently the mass proceeds at least somewhat farther toward fission into two bodies; if it is unstable, apparently this sort of fission is impossible, for when instability occurs the mass will undergo great changes of form and possibly lose its continuity if subject to the slightest disturbance. The conclusion that stability fails before fission is attained is strongly supported by Darwin's investigations on the stability of a liquid satellite,[3] in which he found that a satellite loses its stability before it can be brought near enough to its primary to coalesce with it.

This lengthy review of the case of homogeneous fluids has been given to show (1) that there is no possibility of fission before the pear-shaped figure is reached; (2) that in this simplest of all cases there is not only no proof that fission into two stable masses can ever take place, but that the results reached up to the present point strongly to the opposite conclusion; and (3) that it may be a guide in the more complicated case of heterogeneous compressible masses.

IV. FIGURES OF EQUILIBRIUM OF ROTATING HETEROGENEOUS FLUIDS

We now enter a field beset with formidable difficulties and in which there are but few positive results. We shall consider only those forms of equilibrium which are roughly spherical in form and which have central condensation. The theory of Clairaut[4] shows that for a given rate of rotation and mean density such bodies are more nearly spherical than they would be if they were homogeneous.

[1] "The Stability of the Pear-shaped Figure of Equilibrium of a Rotating Mass of Liquid," *Phil. Trans.*, A, **200**, 251–314, 1903.

[2] *Acad. Imp. des Sci. de St. Petersbourg*, **17**, No. 3, 1905.

[3] *Phil. Trans.*, A, **206**, 161–248, 1906.

[4] See Tisserand, *Mécanique céleste*, **2**, chap. xiii.

The existence of the sun and planets proves their stability, and observations show that they are actually considerably less oblate than the corresponding homogeneous masses would be with the same rates of rotation. The following table gives for the earth, *Jupiter*, and *Saturn* the computed eccentricities of axial sections found from equation (1) and the observed.

	Eccentricity If Homogeneous	Observed Eccentricity
Earth	0.096	0.083
Jupiter	.461	.347
Saturn	.607	.409

With changing rates of rotation the heterogeneous masses go through series of forms of equilibrium analogous to these for homogeneous bodies, and Poincaré's theorems regarding forms of bifurcation and exchange of stabilities still hold.

It is very probable that the central condensation and resulting nearer approach to sphericity tends toward stability. But the actual celestial bodies are composed of compressible fluids, and as Jeans has shown,[1] at least in certain cases, the compressibility tends toward instability. Thus, as compared with the ideal homogeneous masses, the stabilities of the actual masses are subject to two opposing factors. There are at present no quantitative results by means of which we may exactly measure their relative effects; but it is certain that there is no danger of fission until the compressible masses have become more oblate than those we actually find in our system. For purposes of safety, when we are comparing heterogeneous masses with homogeneous ones, we shall conclude there is possibility of fission in the former only when the latter are very far removed from all possibility of fission. Even if some danger as to the results should still remain, we are in the realm of practical certainty when we compare hypothetical masses with the actual forms given by observations.

V. THE CONDITIONS OF EQUILIBRIUM FOR CONSTANT MOMENT OF MOMENTUM

In the mathematical treatments of figures of equilibrium the rate of rotation, ω, is supposed to vary while all the other factors remain

[1] *Phil. Trans.*, A, **201**, 157–184, 1903.

the same. In the actual physical problem as the body condenses the density, rate of rotation, and shape must always be related so that the moment of momentum shall remain constant. We shall impose this condition. Let m represent the mass of the body in question, a its axial radius, σ its density, ω its rate of rotation, $e=\frac{\lambda}{\sqrt{1+\lambda^2}}$ the eccentricity of an axial section, and M its moment of momentum. Then we have

$$\left.\begin{aligned} m&=\tfrac{4}{3}\pi a^3(1+\lambda^2)\sigma\,,\\ M&=\tfrac{2}{5}ma^2(1+\lambda^2)\omega\,. \end{aligned}\right\} \qquad (2)$$

Eliminating a and ω from (1) by means of these equations we have

$$\frac{25\left(\frac{4\pi}{3}\right)^{\frac{1}{3}}M^2}{6k^2m^{\frac{10}{3}}}\sigma^{\frac{1}{3}}=\frac{(1+\lambda^2)^{\frac{2}{3}}}{\lambda^2}\left\{(3+\lambda^2)\frac{\tan^{-1}\lambda}{\lambda}-3\right\}. \qquad (3)$$

When the figure of equilibrium is on the oblate spheroid series its density and oblateness must always satisfy this relation. It is easily shown that when the mass and moment of momentum are given, there is but one value of the density possible for a given oblateness, and but one oblateness possible for a given density. In particular, in any special case, equation (3) enables us to compute the density for which the Jacobian ellipsoids branch. In the homogeneous bodies there is no possibility of fission until long after these figures branch. At the time of branching the axial section of the spheroid has an eccentricity of 0.813; and when the Jacobian ellipsoid branches into the pear-shaped figure the eccentricity of the section through its longest axis and axis of rotation is 0.94, while the axial section at right angles to this is nearly circular. Because of its great elongation the figure which branches from it might better at first be called cucumber-shaped rather than pear-shaped.

In applying (3) we shall assume generally that an actual celestial body will not suffer fission or become unstable until the corresponding homogeneous body, i. e., a body having the same mass and moment of momentum, shall at least have reached the stage where the Jacobian ellipsoid branches. Though this is a very conservative assumption, we shall in some instances use the present oblateness of *Saturn* as the limit within which fission is certainly impossible and stability assured.

VI. APPLICATIONS TO THE SOLAR SYSTEM

Let us first consider the sun and find whether, under cooling and contraction, it can ever split into a binary star. Equation (3) shows that the greater M the smaller the density for which fission will occur. Consequently we shall favor the conclusion of ultimate fission if we introduce simplifying approximations so as to get the computed value of M larger than its true value. The moment of momentum is most easily computed if we assume that the sun is homogeneous, and since it is undoubtedly densest in the central part this assumption will give us a value of M in excess of its true value.

Taking the mean solar day, the mean distance from the earth to the sun, and the mass of the sun as the units of time, length, and mass respectively, we find for the density of water $\sigma = 1{,}567{,}500$, and that for the sun $M = 216 \times 10^{-8}$. The ellipsoids branch for $\lambda = 1.395$. Applying equation (3), we find that the sun cannot arrive at the stage where the Jacobian ellipsoids branch in the corresponding homogeneous mass until its density shall become 307×10^{11} on the water standard. This corresponds to an equatorial diameter of 22 miles (35 km). This inconceivable density, which is thousands of millions of times greater than matter is supposed ever to attain, means that the sun will never arrive at this stage. By a similar computation we find that the sun will not become so oblate as *Saturn* is now until its density shall become 148×10^{10} on the water standard. Its corresponding equatorial diameter is 75 miles (120 km). This means that the sun will always be less oblate and more stable than *Saturn* is now, and that it will never give rise to a binary star by fission. All of this is, of course, under the hypothesis that the sun never will come under the influence of powerful external disturbances, such as would operate upon it if it should pass near another star.

Apparently *Saturn* is more apt to suffer fission than any other member of our system. Taking its mass and period of rotation as $\frac{1}{3502}$ and 10.25 hours, respectively, we find by a similar computation that *Saturn* will not pass beyond limits of safety defined above until its density shall become 21 times that of water. For this figure its polar and equatorial diameters are 16,500 and 28,400 miles (26,600 and 45,700 km), respectively. The high mean density demanded, 28 times that at present, seems to be fatal to the hypothesis that *Saturn*

will ever suffer fission. We find that the density will be 93 times that of water when the pear-shaped figures branch.

From this we see that no member of the solar system will ever suffer fission in the future. But the planets may have originated by fission from a parent nebula, or the moon from the earth in an early state. A quantitative examination of the formulas shows that the latter is the more favorable to the conclusion of fission. Hence we shall examine it.

We observe first that the moment of momentum of the earth-moon system has remained constant except for outside influences. There is none readily assignable which could have increased it. Among those which may have decreased it, apparently solar tidal friction is the only one which can have produced sensible results. In a paper now being published by the Carnegie Institution the writer has computed the maximum effects the sun can have had in this direction in any time however long. Using these results, making simplifying approximations so as to get too large a value for M, then adding 25 per cent. of the computed value as insurance against the possible effects of unknown disturbing forces which may have been acting on it, it is found that in the units defined above $M = 10^{-13}$. In the same units the mass of the earth-moon system is 3×10^{-6}. With these values we find from equation (3) that this hypothetical earth-moon mass would not pass the limits within which there can be no fission until its mean density had become 215 on the water standard, or 40 times the present mean density of the system. It would not even become so oblate as *Saturn* is now until its density had become 10.4 times that of water. Consequently we conclude that the moon and earth have not originated by fission from a common parent mass. In the paper just referred to, the same conclusion was reached by following backward in time the effects of the mutual tides of the system.

VII. APPLICATIONS TO BINARY STARS

Binary stars are relatively so numerous that their evolution is obviously a standard celestial process. We are raising the question whether the process is that of fission. Unfortunately the data at our disposal in treating these systems are so incomplete that our conclusions are not as final as we should desire.

Before taking up explicitly the question of fission, we shall write down some relations which must be satisfied. Consider a spectroscopic binary in which the lines of both stars are visible. For present purposes it will be sufficiently accurate to assume that the orbits are circular. Let i be the complement of the inclination of the plane of the orbit to the line of sight. Let v be the maximum observed relative radial velocity expressed in kilometers per second, and P the period expressed in mean solar days. Then the sum of the masses expressed in terms of the sun's mass must satisfy the relation

$$m_1+m_2=\frac{178Pv^3}{10^8\cos^3 i}\geqq\frac{178}{10^8}Pv^3. \tag{4}$$

Suppose the spectrum of m_1 alone is visible and let v_1 be the maximum observed radial velocity with respect to the center of gravity of the system expressed in kilometers per second. Let $\mu=\frac{m_1}{m_2}$, the ratio of the mass of the bright star to that of the dark. Then

$$m_1+m_2=\frac{178Pv_1^3}{10^8\cos^3 i}(1+\mu)^3\geqq\frac{178}{10^8}Pv_1^3(1+\mu)^3\,. \tag{5}$$

Suppose the two stars have the same density σ. Let a represent the distance between their centers and κa the distance between their surfaces. When P is expressed in mean solar days we have in terms of the density of water

$$\sigma=\frac{2}{100(1-\kappa)^3P^2}\ \frac{(1+\mu^{\frac{1}{3}})^3}{(1+\mu)}. \tag{6}$$

Or, since this is a reciprocal equation in μ whose right member has a maximum for $\mu=1$,

$$\frac{8}{100(1-\kappa)^3P^2}\geqq\sigma\geqq\frac{2}{100(1-\kappa)^3P^2}\,. \tag{7}$$

When $\kappa=0$ the bodies are in contact and this is probably an unstable condition. From Darwin's work on the homogeneous satellite (*loc. cit.*) it seems probable that the smallest value κ can have is about $\frac{1}{3}$. Taking this limit we have

$$\sigma\geqq\frac{27}{400P^2}\,. \tag{8}$$

This formula can lead to little definite information except in the case of very short-period binaries. For example, in the case of β *Cephei*, whose period is 4.57 hours,[1] we find from this relation that $\sigma \geqq 1.86$ on the water standard.

Now let us return to the question of fission of binary stars. Denoting the periods of rotation of m_1 and m_2 by D_1 and D_2, their radii by a_1 and a_2, and assuming that they rotate in the direction of their revolution, the moment of momentum of the system is

$$M = \frac{m_1 m_2 k^{\frac{1}{2}} P^{\frac{1}{2}}}{(2\pi)^{\frac{1}{3}}(m_1+m_2)^{\frac{1}{3}}} + \frac{4\pi m_1 a_1^2}{5D_1} + \frac{4\pi m_2 a_2^2}{5D_2} . \tag{9}$$

The assumption of forward rotation of both masses made in writing this equation is allowable in testing the fission theory, for rotation in this direction would be a consequence of fission. Consequently

$$M > \frac{m_1 m_2 k^{\frac{1}{2}} P^{\frac{1}{2}}}{(2\pi)^{\frac{1}{3}}(m_1+m_2)^{\frac{1}{3}}} . \tag{10}$$

The more nearly equal the two masses are, the more nearly is this inequality an equality for given values of D_1 and D_2.

Let $\frac{m_1}{m_2} = \mu$. Then (10) and (3) give

$$\sigma^{\frac{1}{3}} < \frac{6(3\pi)^{\frac{1}{3}}(1+\mu)^4}{25 k^{\frac{2}{3}} \mu^2 P^{\frac{2}{3}}} \quad \frac{(1+\lambda^2)^{\frac{2}{3}}}{\lambda^2} \left\{ (3+\lambda^2 \frac{\tan^{-1}\lambda}{\lambda} - 3 \right\} . \tag{11}$$

Let us suppose that the two stars are equal, i. e., that $\mu = 1$, as is certainly approximately true in many binary systems. Let us assume that fission will occur at those figures for which the corresponding homogeneous masses branch into the Jacobian ellipsoids. Then the density at the time of fission on the water standard must satisfy the relation

$$\sigma < \frac{0.016}{P^2} , \tag{12}$$

where P must be expressed in mean solar days. If fission should occur only when the pear-shaped figures begin in the corresponding homogeneous masses, we should have instead of (12)

$$\sigma < \frac{0.071}{P^2} . \tag{13}$$

[1] Frost, *Astrophysical Journal*, **24**, 259–262, 1906.

It is obvious from these relations that in all visual binaries in which the periods are at least several years the fission must have taken place, if at all, while the star was yet in the nebulous stage. For example, the period of *α Centauri* is about 81 years, and formula (12) gives for the density of this star, on the water standard, at the time of possible fission $\sigma < 2 \times 10^{-11}$. These results indicate only the order of magnitude. It is significant that they agree with those found in the paper on tides mentioned above. In that paper it was shown that in the case of a binary of two equal masses originating by fission it is not possible for tides to more than double their initial distance, and hence that in such binary systems the initial distances of the two components cannot have been less than half their present distances.

VIII. CONCLUSIONS

Notwithstanding the lack of numerical precision because of the great difficulties of the actual problem in nature, we are justified in concluding that there has been in the solar system no example of the type of fission under consideration here, and that there will be none in the future. In the case of the binary systems the only conclusion reached is that in systems made up of approximately equal pairs and in which the periods are at least several years, fission has taken place, if at all, while the mass was yet in the nebulous state. It is not intended to affirm that any evidence has been brought forward that fission ever occurs. It seems to the writer that in masses with densities decreasing outward from their centers, such as those treated here, fission into two stable masses is extremely improbable. For, suppose a nebula of this type suffers fission. At the moment of separation each of the two parts will be rotating with the same angular speed that the united mass had just previous to the splitting. One of these two parts will have a density not greater than that of the original mass and, therefore, will have at least as great a tendency to undergo fission again, unless either it is in a more stable form or the tides of the other mass tend to keep it from breaking up. If the approximate spheroid is the most stable figure of equilibrium, as seems probable, and if the mass under consideration has suffered fission by evolution along this line of figures, as is assumed, then the former alternative is eliminated. It does not seem reasonable that tidal

forces due to an exterior body could tend to stability, and Darwin's computations confirm this intuition. Besides all this, the binary stars are now bodies with considerable densities. This implies enormous contraction from the nebulous state which, as we have seen, tends still more toward fission. Consequently, it seems that if a nebulous mass with central condensation such as we are considering once suffered fission, it would break up into many fragments. If this view is sound the binaries cannot have originated in this way.

We may still retain the hypothesis that binaries and multiple stars of several members have developed from nebulae, but apparently they must have had originally well-defined nuclei. The photographs of many nebulae support this hypothesis. But we observe that if we are forced to this position we do not explain anything—we only push by an assumption the problem of explaining the binary systems a little farther back into the unknown.

In terminating these remarks it should be noted that in accordance with present-day thought it has silently been assumed throughout that the celestial evolution is from the nebulous state to the stars. This mental attitude has been brought about by a century of unquestioning faith in the Laplacian theory. There are now abundant reasons for rejecting the Laplacian hypothesis as applied to the solar system, and it may be the time is ripe for a serious attempt to see if the opposite hypothesis of the disintegration of matter because of enormous subatomic energies, which perhaps are released in the extremes of temperature and pressure existing in the interior of suns, and of its dispersion in space along coronal streamers or otherwise, cannot be made to satisfy equally well all known phenomena. The existence of such a definitely formulated alternative hypothesis would have a very salutary effect on the interpretation of the results of astronomical observations. We should then more readily reach what is probably a more nearly correct conclusion, viz., that both aggregation and dispersion of matter under certain conditions are important modes of evolution, and that possibly together they lead in some way to approximate cycles of an extent in time and space so far not contemplated.

THE UNIVERSITY OF CHICAGO
December 1, 1908

VERTICAL TEMPERATURE-GRADIENTS OF THE ATMOSPHERE, ESPECIALLY IN THE REGION OF THE UPPER INVERSION

By W. J. HUMPHREYS

GENERAL STATEMENT

The vertical temperature-gradients of the atmosphere, the condition and distribution of its moisture, the direction and speed of the winds, and other upper-air phenomena have long been objects of investigation. Meteorological stations located on hills and on plains, on mountain tops and in valleys, especially when near together, have furnished and continue to furnish much information both valuable and interesting. And for many years this has been supplemented in part by studies of the heights, of the forms, and of the velocities of clouds, and to some extent by records obtained in manned balloons, and still further by the aid of registering instruments sent up in kites. But all the information obtained in these several ways, though of the greatest value to the science of meteorology and to the art of forecasting, has thus far been limited by the upper level of the cirrus clouds. Within this region, however, observations soon made it certain that through a considerable distance next beyond three or four thousand meters above the surface of the earth, changes with altitude are more or less uniform; that in general the moisture constantly decreases; that the winds increase in velocity; and that the temperature fall approaches the adiabatic rate.

The conditions at higher altitudes could only be surmised, but many, by the uncertain process of extrapolation, assumed that the temperature must continue to decrease at about this same rate far out and until it was as low as adiabatic expansion could make it; that the moisture content must gradually decrease to zero; and that the winds in middle latitudes must remain easterly with speeds increasing with elevation. However, the splendid work with sounding balloons by Teisserenc de Bort,[1] by Assmann,[2] by Hoormann,[3]

[1] *Comptes Rendus*, **135**, 897, 1902; **138**, 42, 1904; **145**, 149, 1908; *Quarterly Journal Royal Meteorological Society*, July 1908, p. 189; also many numbers of *Veröffentlichungen*.

[2] *Veröffentlichungen der Internat. Kom. für Wiss. Luftschiffahrt.*

[3] *Ciel et Terre*, 1907–1908; and *Veröffentlichungen*.

by Rotch,[1] by Peteval,[2] and by many others has shown these assumptions to be radically wrong.

BALLOON RECORDS

During the past ten years hundreds of sounding balloons, equipped with suitable registering apparatus, have been sent up under widely different conditions to various heights; many to fifteen kilometers, some to twenty kilometers, and a few to even higher levels. The records represent flights by day and by night made in all sorts of weather and in every season of the year; flights over continental, island, and ocean regions; and flights at different latitudes from the tropics to beyond the arctic circle; and besides, the apparatus used has been by several makers and of different design. In this way disturbances due to location and to storm influence have been detected and systematic instrumental errors largely avoided. But the results of all the observations are in general accord, and show that the explored portion of the atmosphere consists of three more or less distinct regions.

I. The region of terrestrial disturbance, extending from the ground to an elevation of, roughly, 3000 meters above its surface, in which the temperature-gradient usually is very irregular and often locally reversed. This is also the principal region of cloud formation and of precipitation.

II. The region of uniform changes, lying, roughly, between the upper limits of I and the 10,000-meter level above the sea, in which the temperature-gradient, nearly constant, approaches the adiabatic. This region is comparatively free from condensation and precipitation, since it lies above the average nimbus cloud while the cirri float in only its topmost portion. At times it is the seat of vertical convections of varying extents and intensities, but its normal condition is one of stability as shown by its usual freedom from clouds, and as necessitated by the negative departure of its temperature-gradient from the adiabatic.

III. The region of permanent inversion, or all that explored portion above the 10,000-meter level or thereabouts. Here the temperature-gradient is small and usually positive, and vertical convection therefore is always impossible.

[1] *Nature*, **78**, 7, 1908. [2] *Ibid.*, p. 56.

In the region of terrestrial disturbance, that is, in the lower or denser portions of the atmosphere, the winds are irregular, and commonly differ in both speed and direction above and below any, other than a mere surface, inversion. In all essentials they are chiefly determined by the locations and intensities of barometric highs and lows. The highs and the lows continue to play an important part, even far up in the region of uniform changes, but are less and less effective as the elevation is increased. In the upper portion of this region the great planetary circulation mainly prevails as shown by the movements of the cirrus clouds which are near its upper limit. It is known, too, from the drifting of balloons, and from observation on clouds, that in this region the wind moves faster and faster with increase in elevation, and easterly in extratropical countries. Above the inversion level the velocities of the winds are much less[1] than they are immediately below it. On passing up from the one region into the other this velocity usually is found to drop by from 25 to 80 per cent., and apparently the directions in the two places have but little interdependence. Besides, the air above the place of inversion seems always to be excessively dry[2] no matter what the humidity may be at lower levels.

The height, generally sharply defined, of the place where the upper inversion begins, like its temperature, is a function of season, of latitude, of barometric pressure, and probably of still other conditions. It is high up in a well-formed "high" and correspondingly low in a "low." It is at greater elevations and higher temperatures in summer than in the winter, and descends with increase of latitude from the tropic to the polar regions. The higher it is found above the earth, season and other things being equal, the lower in general is its temperature, and conversely the lower it lies, under similar conditions, the warmer it is.

We therefore have two distinct atmospheres that intermingle but slightly: a lower or inner turbulent one with a large negative temperature-gradient, and an upper or outer one with a small positive gradient, floating on the first like oil on water. The lower contains from two-thirds to three-fourths of the entire mass of such gases

[1] Bassus, *Beiträge zur Physik der freien Atmosphäre*, **2**, 92, 1908.

[2] Kleinschmidt, *ibid.*, **2**, 205, 1908.

of the air as oxygen, nitrogen, and all the members, except helium, presumably, of the argon family; a still greater proportion of the carbon dioxide, and nearly all the water vapor. It is warm in its lowest portion, but cools, irregularly at first then rapidly and nearly regularly, with increasing elevation to a minimum of from $-40°$ C. to $-70°$ C. The upper atmosphere contains extremely little water vapor, and its temperature rises sometimes abruptly at the start and then slowly, but usually slowly all the way with elevation from the place of inversion to an unknown temperature at a height not yet reached. Occasional observations indicate an isothermal condition, and for this reason the outer atmosphere is often called the "isothermal layer," and a few observations have shown even a slow cooling with elevation, but both these conditions are unusual.

The region above the upper inversion cannot appreciably be penetrated by convection currents from the air below, since this would cause a cooling by expansion of the rising mass to a temperature lower than that of the surrounding medium, so that under the same pressure or at the same level its density would be greater than that of the adjacent air; and therefore all storms, all condensation, all abnormal and irregular moisture distribution, and virtually all dust, except that of meteors and of violent volcanic eruptions, are limited to the lower atmosphere. The upper atmosphere, floating on the lower, will rise and fall as a whole with the latter, but with more or less mixing of the contiguous portions of the two. Upward currents of air, when they reach the inversion surface, are forced to spread out under it somewhat as warm air in a room spreads out next the ceiling, since, as explained, they cannot rise any farther; and doubtless this air carries with it the moisture for the highest cirrus clouds, because, like the inversion layer, they approach nearer the earth in colder regions, nearer in winter than in summer, and are highest toward the end of a clear warm spell of weather.

Much of the above is well illustrated by the temperature-gradient curves of Fig. 1, which is copied, with slight additions, i. e., curves 7 to 10, inclusive, from the *Annuaire météorolgique pour 1908* (Obser vatoire Royal de Belgique).

The flights giving these curves were made from Uccle near Brussels, only 100 meters above sea-level, and with a number of others made

at other times (for these include all that were made within the dates given) have been reported in detail by Hoormann in *Ciel et Terre*.

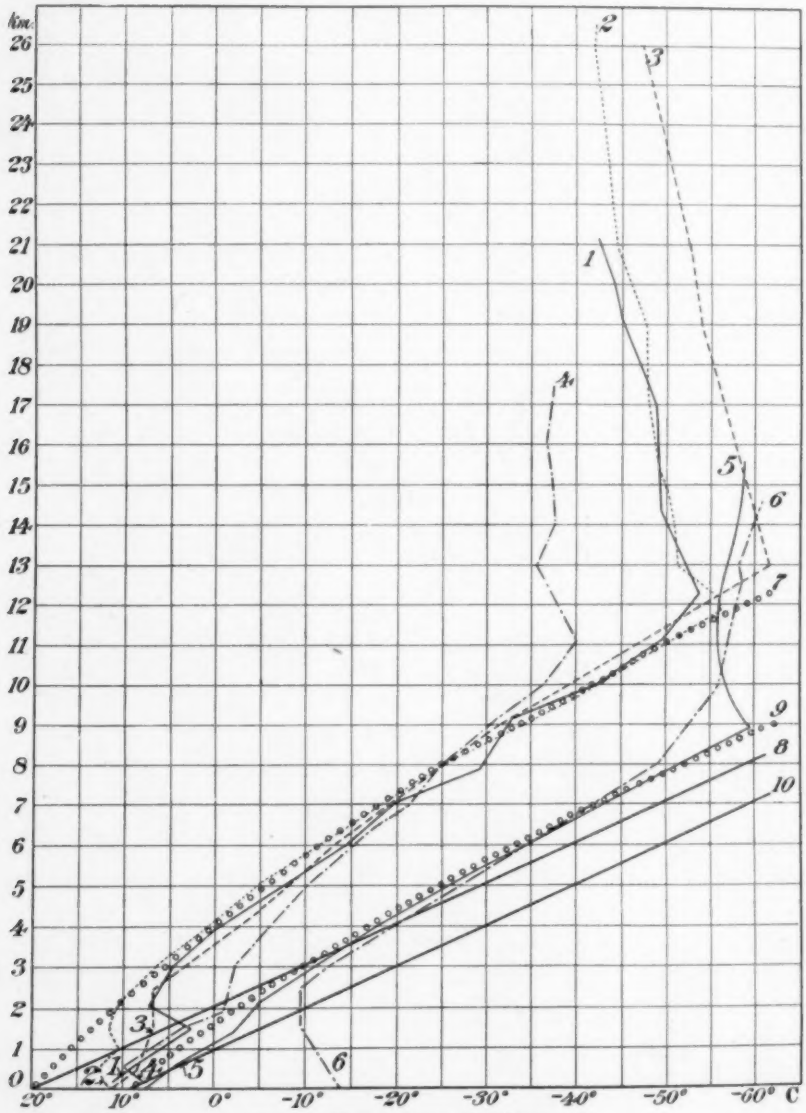


FIG. 1.—Temperature-Gradients.

The following table contains some of the more important data in connection with these ascensions. The temperature-gradient is for

the region of uniform changes. The flight of July 25 lasted two and a half hours; the others about two hours each.

No. of Curve	Date	Hour of Starting	Condition of Sky	Barometer at Station	Weather	$\frac{\Delta t}{100m}$ Region of Uniform Changes
1...	July 24, 1907	7 A. M.	Covered; strato- and fracto-cum.	751.5	Neutral	0°.68 C.
2...	July 25, 1907	7 A. M.	4 tenths cirrus	751.0	Neutral	0.70
3...	Sept. 5, 1907	7 A. M.	Covered; alto-strat. fracto-cum.	754.0	Neutral	0.66
4...	Oct. 3, 1907	7 A. M.	Covered; stratus	744.0	Cyclonic	0.50
5...	Dec. 12, 1907	after sundown	Covered (?)	740.0	Cyclonic	0.83
6...	Jan. 3, 1908	7 A. M.	Serene	760.0	Anti-cyclonic	0.71

Curve 8, a straight line, gives the adiabatic gradient for dry air, and curve 7 gives the temperature-gradient for saturated air, both starting at sea-level with a temperature of 20° C. Curves 9 and 10 are the same as 7 and 8, respectively, except that the initial temperature is assumed to be 9° C. Curves 1 to 3, inclusive, give a summer group, while 5 and 6 represent winter gradients. It will be noticed at once, and this is generally true, that the winter curves have a slope intermediate between the dry adiabatic and those of summer, and that the temperature-gradient is distinctly less in summer than it is in winter. It will also be noticed that the upper inversion is located higher in summer than in winter; that, of the summer gradients, No. 3 had the highest barometer and inverted at the greatest altitude, and that a cyclonic condition, or low barometer, lowers the place of inversion; further, that the higher the inversion, at any season, the less its temperature; and conversely. The place of inversion usually, and in all these curves except No. 6, is rather sharply defined.

THEORY

Irregularities in the temperature-gradient of the lower atmosphere.— The thermal irregularities and local inversions of the lower atmosphere are caused by wide temperature changes in the surface of the earth, by the over-running and by the under-running of warm and of cold masses of air, and by the action of cloud layers in changing

the position of insolation from the earth and from the denser portions of the atmosphere to higher levels.

Morning inversions.—The inversion so commonly found in the early morning is due to the fact that the surface of the earth radiates more freely than does the atmosphere at the same temperature, and that therefore at night, especially when the sky is at all clear, it cools correspondingly lower, and also cools the atmosphere for some distance above it to an extent depending largely upon the humidity, degree of cloudiness, and wind velocity.

The more humid the air the less the depth to which earth radiation can directly penetrate, and therefore the more slowly, because of counter radiation, it gets away. Clouds check the loss of heat mainly by reflection; while the winds by mixing the air of different levels prevent excessive cooling at the surface.

The effects of this nocturnal cooling are well shown by the curves, as explained above. Flight No. 5, made just after sundown, of course shows no such disturbance.

Departure of gradient from the dry adiabatic.—Although the atmosphere constantly is in a state of more or less turmoil, its average temperature-gradient, even in the region of uniform changes where this is greatest, is less than the adiabatic of dry air; due partly to the heat it absorbs in the form of earth and of solar radiations—an amount which during the day is in excess of the corresponding loss—but chiefly to the fact that the air is not dry, and that it therefore receives much heat as it rises, from condensation of the moisture it contains. This liberated sensible heat, by all processes of distribution, conduction, convection, and radiation, extends to and warms the colder masses above, and decreases by counter-radiation the loss of heat from lower levels. The temperature-gradients are modified most in the lower atmosphere where the average percentage of saturation is greatest, and where, because of the temperature, its water capacity is large.

Curves 7 and 9 show how closely the actual normal gradients follow saturation paths, even though actual saturation seldom exists except in the midst of clouds, and how widely they depart from lines 8 and 10, that correspond to dry adiabatic expansion.

Seasonal difference in temperature-gradient.—The conditions that

determine the departure of ordinary air gradients from those of dry air, insolation, and moisture content, are more pronounced in summer than in winter, and therefore summer gradients should differ from winter ones in being still farther removed, as they actually are, from the adiabatic curve of dry air.

Storm gradients.—A summer cyclone furnishes the extreme of departure from dry-air conditions, and therefore also yields the extreme gradient departure from the dry adiabatic, as illustrated by curve 4. It even sets free much heat in the rainy sections by condensation of moisture drawn in by the winds from distant regions. Two centimeters of rain, for instance, will free as much heat as the surface of the earth would receive in sixteen clear summer noon hours of sunshine; and practically all this heat goes to the higher atmosphere, as the lower levels and the ground are not warmed by the rainfall, but rather cooled by its evaporation, and because of the lower temperature it had when it left the clouds, and often by the under-running of masses of cold air.

The upper and the lower parts of curve 4 illustrate these effects.

Cause of the upper inversion.—Several attempts have been made to account for the upper inversion. Probably the earliest is that of Assmann,[1] who suggested that the warm air above the inversion level is a part of the world circulation from the equator to the poles.

Several objections can be offered to this theory; among them the fact that the level of the inversion surface and the temperature of the air above it are functions of the conditions of the lower atmosphere; and that it is not supported by the directions of the warm upper-air currents, which often are from northerly[2] points, and are in fact irregular[3] both as to direction and as to speed.

Nimführ[4] made a slight modification of Assmann's theory when he suggested that the isothermal layer is due to a downward component of the air, together with its movement from the south. But the above objections also apply to this theory.

Fényi[5] makes the plausible suggestion that it is due to the absorp-

[1] *Sitzungsberichte der kön. preus. Akad. der Wiss.*, **1902**, 495.

[2] Hergesell, *Beiträge zur Phys. der freien Atmos.*, **1**, 143, 1905.

[3] Bassus, *ibid.*, **2**, 92, 1906.

[4] *Meteorologische Zeitschrift*, **23**, 245, 1906.

[5] *Ibid.*, **24**, 355, 1907.

tion in the outer atmosphere of an unknown amount of ultra-violet light. But observations by Abbot and Fowle[1] indicate that the absorbed ultra-violet portion of the sun's energy is of the order of only 2 per cent., or less, of the total insolation; and therefore even if there was no loss by radiation or otherwise, it would in twelve hours heat the air of the isothermal layer by less than half a degree C.; an amount insufficient to account for the observed temperatures.

Trabert[2] holds that possibly the vertical temperature-gradient is less above oceans than above continents, and that therefore the upper inversion may be due to this relatively warm air as it sweeps over the land. But it is not clear how this can account for the increase of temperature beyond the minimum layer, nor is it supported by the irregular directions of the winds in the upper region, and finally the inversion is as definitely found over the oceans themselves as anywhere else.

Very[3] ascribes the isothermal condition to the absorption of lines and bands of water vapor. A fatal objection to this theory, however, if the observations are correct, is the fact that the water vapor is not there to absorb[4]—certainly there can be but little at an elevation of 26 kilometers, at which elevation the temperature is still increasing. Teisserenc de Bort[5] has suggested that the "isothermal layer" is due to the fact that there is in this region but little vertical convection. It seems, however, more probable that the absence of convection is a result rather than the cause of this warm layer.

Gold[6] claims that an explanation of the existence of the "isothermal layer" must take into account the radiation of the atmosphere, and gives conclusions, which he says follow from certain assumptions as to its absorption, so suggestive as to make a fuller paper from him on this subject very desirable.

Assuming balloon observations correctly to represent conditions as they actually exist, it is interesting to find their physical basis, and to the practical meteorologist extremely important to do so, since

[1] *Annals of the Astrophysical Observatory of the Smithsonian Institution*, **2**, 56.
[2] *Metl. Zeitschrift*, **24**, 504 and 565, 1907.
[3] *Phil. Mag.* (6), **16**, 467, 1908.
[4] Kleinschmidt, *Beiträge zur Phys. der freien Atmos.*, **2**, 205, 1908.
[5] *Nature*, **78**, 551, 1908. [6] *Ibid.*, **78**, 551, 552, 1908.

the chief hope for improvement in forecasting rests upon an increase in our knowledge of the causes and of the effects of atmospheric phenomena. And since these involve the transfer and the transformation of energy, it is necessary first to determine the whence and the whither, as well as the amount and kind of this energy supply.

A little energy reaches the atmosphere by conduction from the heated interior of the earth; some from the omnipresent radioactive elements; a little as a result of meteoric bombardment, and possibly an additional small amount through solar electrons, but the sum total from these and from similar sources is negligibly small. Even the combined radiations of all the stars, exclusive of the sun, is estimated to produce in space an effective absolute temperature of only a few degrees C.; not less than two, probably, nor more than ten.

Hence the supply of energy to the earth is almost wholly of the radiant form from the sun, and, neglecting trifling losses otherwise, equilibrium is maintained by a correspondingly intense reflection and radiation from the earth to space. The causes therefore of many atmospheric conditions, among them the existence of the upper inversion, are to be found in the phenomena of absorption and of radiation as they pertain to the substances concerned and to the particular limits of wave-length and of temperature involved.

Solar energy, excepting a small amount, as it reaches the earth's atmosphere, is confined to wave-lengths ranging from 2.5 μ down, with the maximum intensity somewhere between 0.4 μ and 0.5 μ. The extent to which this energy is absorbed by the gases surrounding the earth is not an easy matter to determine, since it depends upon the wave-length, upon the kind of gas and its temperature, upon the amount of the gas through which it passes, or its partial pressure, and even upon the total[1] pressure to which it is subjected; nor is it certain that these are all the modifying conditions. Still, due mainly to the Astrophysical Observatory of the Smithsonian Institution, very much is known about this problem.

On the violet side, as it reaches us, the energy curve is very steep, and vanishes for ordinary levels at about 0.3 μ. It is also steep on the red side, so that roughly three-fourths of the total energy lies between 0.4 μ and 1.1 μ. The extreme ultra-violet portion of the

[1] Ångström, *Arkiv för Matematik, Astronomi och Fysik*, **4**, No. 30, 1908.

insolation, of which there can be no reasonable doubt, is wholly absorbed by the outer dry portions of the atmosphere, as are also certain narrow regions, such as make up the oxygen lines in the red. And besides, a general, though less and less absorption extends to regions nearer and even into the visible spectrum.

Lower down in the atmosphere water vapor absorbs particular groups of wave-lengths amounting in all to from 5 to 10 or 12 per cent. of the whole energy. The rest is absorbed or reflected by clouds, by dust, or by the surface of the earth. That portion of course of the reflected light which returns to space retains its original wave-lengths. The absorbed part of the energy, however, escapes as earth radiation of long wave-lengths from 4 μ to 20 μ mainly, with the maximum intensity not far from 12 μ. For all these water vapor, according to Rubens and Aschkinass,[1] has a large coefficient of absorption, and for a few of them so has carbon dioxide; so that radiation does not escape to any great extent directly from the earth, nor from the air or clouds of lower levels, but chiefly through a step-by-step process, as each layer radiates to those above and these in turn more and more freely to space through the remaining water vapor and the outer dry atmosphere, where the coefficient of absorption certainly is small. For a discussion of this point see *Annals of the Astrophysical Observatory of the Smithsonian Institution*, Vol. II.

Since the horizontal layers of the moisture may be regarded as absorbers of energy, and as radiators, it is easy in a general way to consider the action of a given layer in sending radiation to say a unit horizontal area at any position above or below it.

Let S be a unit area parallel to, but any distance from, a flat radiating surface of infinite extent; and let I be the radiation intensity of the plane, that is, the total upward radiation in all directions from a unit surface, divided by 2π, and let θ be the angle of incidence of a ray on this unit area. Then, in the absence of any absorption, the total radiation normal to S is

$$R = 2\pi I \int_0^{\frac{\pi}{2}} \sin\theta \cos\theta d\theta = \pi I.$$

Let now a uniformly absorbing layer of constant thickness t be placed parallel to the radiating plane, but between it and S. Then

[1] *Annalen der Physik*, **64**, 598, 1898.

the length of that portion of any ray within this layer on its way to S is

$$l = t \sec \theta .$$

If a is the coefficient of absorption, that is, in the case of normal radiation, the ratio of the energy absorbed by a layer of unit thickness to the incident energy, then the portion absorbed by a layer of thickness l is $1-(1-a)^l$, but when a is small and l not too large, this is approximately $la = at \sec \theta$; and therefore in this case,

$$R = 2\pi I \int_0^{\frac{\pi}{2}} \sin \theta \cos \theta d\theta - 2\pi I at \int_0^{\frac{\pi}{2}} \sin \theta d\theta = \pi I (1 - 2at).$$

These equations give the intensity of the radiation from the initial surface normal to A in terms of experimentally determinable quantities and show that while it is a function of the absorbing layer, it is, nevertheless, in each case independent of the distance from the radiating surface. The absorbed energy, however, is re-radiated, so that the sum total of the outgoing energy is a constant.

Therefore above the plane of the upper inversion, that is, above the moisture of the atmosphere, or the region in which solar energy is mainly absorbed, the radiation normal to a horizontal area from any plane below is, neglecting the slight absorption of the dry air through which it passes, approximately independent of its position, so long as its distance above this plane is small in comparison with the radius of the earth, as of course that of every point so far reached really is. And, as explained above, when equilibrium is established the total radiation to this surface is independent of absorption.

In considering the temperatures in the region of the upper inversion the effects of earth radiations, $\lambda\epsilon$, and of solar radiations, λs, will be examined separately, because the latter, besides being active only half the time, produce results other than heating alone, and therefore the Stewart-Kirchhoff law of radiation and absorption is not applicable to them; while so far as known it is applicable to the former, which also are continuous in their action both day and night.

Since convection necessarily is absent above the upper inversion, and since the thermal conductivity of gases is very small, therefore anything beyond this plane is in the position, nearly, so far as earth radiation is concerned, of a body receiving radiation from a flat, black

surface of infinite extent; because the water vapor below is black to long waves, the only kind given off by objects at the prevailing low temperatures.

Consider first the condition of an object placed between two such surfaces, parallel to each other and close together in comparison to their linear dimensions. Let their temperature be T_2 absolute; then whatever the object placed between them, its temperature will become T_2 also, because it is practically surrounded by walls at this constant temperature.

Now let a slab of this substance, say one centimeter square, δt thick, be placed parallel to the large planes, and let H_2 be the number of heat units of wave-length $\lambda\epsilon$ they supply to it per second, and let A_2 be the number of units of this energy it absorbs per second. Then if E_2 is the number of units of energy of the same wave-length it radiates per second, as a result of its hotness only, the following equation is given by the Stewart-Kirchhoff law:

$$\left(\frac{\frac{E_2}{A_2}}{H_2}\right)_{\lambda\epsilon,\, T_2} = (R_2)_{\lambda\epsilon,\, T_2} = \left\{\begin{array}{l}\text{The number of heat units a black body radiates per second within the given range of wave-lengths (under the given conditions the total radiation) when at temperature } T_2.\end{array}\right.$$

But the state is a steady one, and therefore $E_2 = A_2$, and $R_2 = H_2$.

Now let one of the parallel surfaces be removed and the other retained at its old temperature T_2. The heated body, small slab, will come to a new state of equilibrium at a temperature T_1, and give the relations

$$\left(\frac{\frac{E_1}{A_1}}{H_1}\right)_{\lambda\epsilon,\, T_1} = (R_1)_{\lambda\epsilon,\, T_1}, \quad E_1 = A_1, \quad \text{and} \quad R_1 = H_1.$$

Since H_2 is the radiation per second incident on the heated body from the two planes jointly, while H_1 is the corresponding amount from but one of them at the same temperature, then evidently

$$\frac{H_2}{H_1} = \frac{R_2}{R_1} = \frac{2}{1}.$$

But from the Stefan-Boltzmann law we know that

$$\frac{R_2}{R_1} = \frac{T_2^4}{T_1^4} = \frac{2}{1};$$

and hence

$$\frac{T_2}{T_1}=\frac{119}{100}, \quad \text{approximately.}$$

The second condition above described, that is, the single radiating black surface heating an object in its neighborhood, is analogous to the effective radiating surface of the earth at temperature T_2 and the dry diathermanous atmosphere above the surface of the upper inversion at temperature T_1.

Since the absorption of the dry atmosphere is minute the value of T_1, if determined by earth radiations alone, would be nearly constant —though of slowly decreasing value—with increase of elevation. A knowledge of these two temperatures should, therefore, show to what extent the temperature of the upper air is determined by that of the effective radiation surface. And both are known: the latter calculated by Abbot and Fowle[1] from the results of many observations made chiefly by them at the Astrophysical Observatory of the Smithsonian Institution, and the former directly obtained with sounding balloons. The temperature of the upper inversion varies through a considerable range, but averages something like $-55°$ C. Therefore, assuming this to be due entirely to earth radiation, we get

$$\frac{T_2}{218}=\frac{119}{100} \quad \text{or} \quad T_2=259° \text{ Abs.}, \quad \text{approximately.}$$

But this is about the temperature[2] required by the solar constant for the effective radiating layer, that is, a layer of dense water vapor—the equivalent nearly at this temperature of a black surface—that radiates the given amount of energy; and therefore it seems that in the main the temperature of the upper air is due to radiation from the moisture of the lower levels and that the dry air is extremely diathermanous.

The effective temperature, or temperature of the effective layer, is found in middle latitudes about three kilometers above the surface of the earth in the winter and five in the summer, or say four kilometers for the year.

Consider now the effect of the solar radiation on the outer atmos-

[1] *Annals of the Astrophysical Observatory of the Smithsonian Institution*, 2, 174.

[2] *Ibid.*

phere. The oxygen of this region absorbs the ultra-violet and a little of the red, and besides slight heating, produces, it is believed, electrical and chemical effects. That is, it is thought that the air is ionized and that both ozone[1] and nitrogen pentoxide[2] probably are produced. The blue of the sky would then be due in part, as many have suggested, to this ozone. Each of these compounds, but especially ozone,[3] has absorption bands scattered through a wide range of the spectrum from well within the ultra-violet to 12 μ or farther in the infra-red. It has a strong band at and below 0.3 μ that may account in part for the sharp limitation near this wave-length of the observed solar spectrum. It has another well-defined band at 0.6 μ, which possibly adds something to the great depression found in the solar intensity curve at this place. There are several other bands, but in the infra-red, one of which 8.5 μ to 10.5 μ is very strong, and of course would absorb earth radiations.

Spectroscopically then, assuming the existence of ozone in the high atmosphere, for which there is much evidence, the known part of the earth's atmosphere is divisible into three regions: the black body, the diathermanous, and the selectively absorptive. The first is the water-vapor region which totally, or nearly so, absorbs long-wave radiations. The second is the dry air just above this region; and the third is the high atmosphere, presumably rich in ozone, in which absorption is marked but selective. There is reason to believe, however, that the outer atmosphere shades away in density with elevation and changes in composition, until at a height of one hundred kilometers or less it is again diathermanous, with nothing but a little hydrogen and possibly some helium left.

Since both ozone and water vapor transmit solar radiation fairly well, most of it reaches the lower levels and the earth, where it is absorbed, and there emitted again as long waves for which water vapor is nearly opaque. *In this way the lower atmosphere becomes heated and rises, in which act it cools by expansion and by radiation until it reaches a minimum temperature determined mainly by the*

[1] Lyman, *Astrophysical Journal*, **27**, 87, 1908; Henriet et Bonyssy, *Comptes Rendus*, **146**, 977, 1908.

[2] Warburg und Leithäuser, *Annalen der Physik*, **23**, 209, 1907.

[3] Ladenburg und Lehmann, *ibid.*, **21**, 305, 1906.

sum total of the energy emitted from lower levels. Above this place the temperature slowly rises, presumably because of the absorption, as explained, due to oxygen and to ozone.

The lower levels of the upper atmosphere should be comparatively free from ozone, partly because it is less rapidly produced at these levels, and partly because it slowly reverts into ordinary oxygen. Besides, a small amount of water vapor must diffuse across the inversion plane, since it extends in appreciable quantities to this level, as we know by the cirrus clouds; and it is probable that this water vapor, as it comes in contact with the ozone of the inversion region, converts it by way of hydrogen peroxide into ordinary oxygen. These two processes, the spontaneous and the chemical reduction of ozone to oxygen, would keep this place constantly diathermanous. Presumably, too, above the limits of the water vapor, where the oxygen absorption of the ultra-violet is greatest, the largest amounts of ozone are found. If so, then this region will absorb a larger amount of solar energy as well as more of the earth's radiation than will the diathermanous layer below, and thus be kept constantly warmer. Besides this, difference in temperature may be somewhat accentuated, or at least maintained, at night by the rapid radiation through the outer atmosphere of the upper levels of the water vapor, causing it to cool more rapidly than the air above it, in a manner analogous to the radiation phenomena involved in the formation of anchor ice, and of morning inversions at the surface of the earth.

Cause of abrupt change of temperature-gradient.—The sharp definition of the place of inversion probably is due to the existence at that level of a more or less well-formed cloud veil, which becomes to that extent the locus of insolation. If so, then a sky with extensive cirrus clouds should give immediately above the inversion—presumably the upper surface of the cirrus—a rapid increase of temperature with elevation, while a serene sky should furnish a curve of gradual transition from the one gradient to the other. Both these conditions and results are shown by the curves, which are in harmony with other flights under similar circumstances. No. 2 shows the effect of cirrus clouds, and No. 6, the gradient when the sky is perfectly clear. In the one the change is gradual; in the other it is abrupt and the increase large.

Cause of seasonal difference in height of inversion.—During the summer the moisture content of the air, because of increased temperatures, is greater than it is in winter, and extends to greater elevations, and therefore the effective radiating surface is correspondingly elevated. This combined with the difference in the gradients for the two seasons—less in summer than in winter—puts the inversion level at its greatest elevation during the warmer weather.

Cause of seasonal difference in temperature at inversion surface.—The lower atmosphere and the surface of the earth receive more solar energy during the summer than in the winter, and consequently must radiate more at this season. Therefore, if the inversion temperature is determined mainly, or even largely, by earth radiation, it should be greatest in summer and least in winter; and this is supported by the published observations from Trapps, from Uccle, and from Strassburg, and presumably, therefore, is generally true.

Cause of latitude effect on height of inversion.—Change in latitude at any given season is analogous, meteorologically, to change of season at any given latitude, and might be expected to lead, as it does, to a corresponding change in the height of the inversion.

Cause of relation between barometric pressure and height of inversion.—Normally the region of high barometer is one of clear weather, while a low barometer is accompanied by precipitation, which correspondingly heats the upper air, and decreases its temperature-gradient. As a result of this heating, the place of inversion is shifted to one of lower level and higher temperature, as is well illustrated by curve No. 4.

CONCLUSIONS

1. Considered from the standpoint of temperature-gradients, the explored portion of the atmosphere is divisible into three parts: (*a*) the region of terrestrial disturbance, extending from the ground to an elevation of about 3000 meters above its surface; (*b*) the region of uniform changes, from the top of (*a*) to roughly 10,000 meters above sea-level; (*c*) the region of permanent inversion, or all that explored portion, at least, that lies above the plane of the upper inversion.

2. Spectroscopically the known atmosphere is divisible into

three parts: (*a*) the black body portion, coincident with the region of and due to the relatively dense water vapor; (*b*) the diathermanous, or the dry air next above the water vapor; (*c*) the selectively absorptive, or the air of the isothermal layer, presumably rich in ozone.

3. The isothermal layer is due mainly to earth radiations. The lower heated air rises and cools by expansion until it reaches a minimum temperature fixed by the radiation from below at that time and place.

4. The differences in the temperature-gradients of the region of uniform changes, the differences in the heights of the plane of inversion, and in the temperatures at which inversion takes place, as determined by season, by latitude, and by storm conditions, are all accounted for by the corresponding differences in the moisture content and in the radiation of the atmosphere.

5. The temperature and the height of the upper inversion are given by the equations

$$T_1 = 0.84 T_2 ,$$

and

$$h_1 = h_0 + \int_{T_0}^{T_1} \frac{dh}{dT} ,$$

in which

h_0 = any initial height. It may be the surface of the earth.

h_1 = the height of the inversion surface.

$\frac{dh}{dT}$ = the reciprocal of the temperature-gradient where the temperature is T.

T_0 = the absolute temperature at the elevation h_0.

T_1 = the absolute temperature at the level of inversion, h_1.

T_2 = the absolute temperature of the effective radiating surface, or of a dense layer of water vapor radiating the given amount of energy.

SUGGESTIONS

Much needs yet to be done in observing temperature-gradients during special types of weather, particularly in the centers and about the borders of cyclones. It would also be well to take the height of the high cirrus at the time the ascension is made.

Many laboratory investigations are also desirable in connection with the absorption and radiation of the several gases and vapors

of the atmosphere, singly and variously combined, at different pressures and different temperatures. The investigations indicated would necessarily be long, and some of them most difficult, but only in so far as they and kindred ones are completed, can meteorological problems of the nature of those discussed in this paper be fully solved.

The substance of this paper was read July 1, 1908, before the Physics Section of the American Association for the Advancement of Science,[1] and again on August 27, 1908, before the Astronomical and Astrophysical Society of America.

MOUNT WEATHER OBSERVATORY
VIA BLUEMONT, VA.
October 1908

[1] *Science*, **28**, 256, 1908.

THE CONSTITUTION OF THE SUN[1]

By J. F. HERMANN SCHULZ

My theory is based upon the lines laid out long ago by Kirchhoff thus:

> The most probable assumption which can be made is that the sun consists of a solid or liquid nucleus in the highest state of incandescence, surrounded by an atmosphere of somewhat lower temperature.

This assumption later on was modified and extended by Zöllner thus:

> The sun is a glowing *liquid* body, surrounded by a glowing atmosphere; in this latter floats a sheet of luminous, cumulus-like clouds, constantly being renewed, at a certain distance above the liquid surface.

When Zöllner in 1873 expressed this view, it appeared nearly impossible to speak in earnest of a *liquid* solar nucleus At that time the most extravagant figures were still mentioned as to the temperature of the sun.

Zöllner himself found 1 to 2 millions of degrees Centigrade as a minimum temperature for the gases of the prominences before their escape out of the liquid body into the open solar atmosphere, whereas Secchi went still farther, and came up to 40 million degrees C.[2]

Now at such temperatures, or even at only a hundred thousand degrees, there is practically no basis for the assumption of a liquid sun, but today the matter stands at a widely different point.

The readers of this *Journal* will be well aware that the latest calculations, based upon the most reliable determinations of the solar constant, combined with the Stephan's law of radiation, give us less than 6000° C. as *mean temperature of the radiating layers.* Millochau and Féry find 5620° absolute, or 5347° C.[3] We do not speak of the temperature of the sun, for it is clear that the measured solar

[1] About twenty years ago I advanced a theory of the sun, at first in the *Gaea*, edited by Dr. Hermann J. Klein of Cologne, in 1885 and 1886, afterward in the *Astronomische Nachrichten*, **119**, 1887 and 1888, which latter papers were reprinted in Exner's *Repertorium der Physik*, **25**. As this theory may appear more plausible now than in those days, I venture to bring it again before the notice of astrophysicists.

[2] *Die Sonne*, p. 573.

[3] *Comptes Rendus*, **143**, 570, 1906.

radiation on the earth is not simple but is the combined radiation (1) of the true gaseous atmosphere; (2) of the photospheric clouds—c ndensed particles; and (3) of the liquid nucleus

From this assumption we are able to explain correctly the fact that the intensity of solar radiation diminishes from the center of the disk toward the limb. Near the limb we get radiation only from the atmosphere and the tops—the least heated parts—of the photospheric clouds, whereas in the central portions of the disk, we are looking down into the gaseous interstices between these clouds, and thus here get also radiation from the lower, hotter parts of same, as well as also from the still hotter liquid nucleus. This is a real explanation of the observed fact, whereas the usual absorption hypothesis does not stand a closer test. I pointed out in *Gaea*, p. 430, 1886, and in *Astronomische Nachrichten*, Nos. 2817, 2818, 1888, that absorption does not mean simply annihilation, and that, since the solar atmosphere certainly is not absolutely diathermous, a certain absorption must also originally have taken place in the outer cooler layers. These layers thereby were heated and their proper radiation increased until a state of equilibrium was reached, where absorption and their own radiation became equal throughout the entire atmosphere, and thus no diminution of the radiation as a consequence of absorption could be spoken of.

As generally the absorbed energy is transformed into radiation of longer wave-length, it is clear that the luminous, and still more the ultra-violet radiation must be weakened by the process described, but the total value of the radiated energy cannot be affected after the state of equilibrium between absorption and radiation is reached.

Recently also Julius[1] and W. Wundt[2] have come to the same conclusions as those I advanced twenty years ago.

From these considerations follows also necessarily a very important fact, namely, that the solar atmosphere cannot be in the adiabatic state, but that the upper strata must possess a relatively higher temperature—thence would also follow a greater extension of the atmosphere than would be otherwise possible—and finally, that it is impossible to explain any cooling in lower levels—such as sun-spots would require—by descending currents in the atmosphere. The

[1] *Astrophysical Journal*, **23**, 323, 1906.

[2] *Physikalische Zeitschrift*, **7**, 385, 1906.

differences in temperature between various levels must be far less than usually anticipated.

We now come to consider whether at a mean temperature of about 5400° C. we are allowed to imagine reasonably a truly liquid nucleus of the sun.

If about 5400° C. be the *mean* temperature, the upper surface of the photosphere must be at a lower, the liquid nucleus, however, at a higher temperature, the latter thus perhaps still above 6000° C. The late Henri Moissan expressed his view in the *Comptes Rendus* (**142**, 673, 1906) that the temperature of the liquid nucleus of the sun—which he adopts in conjunction with Birkeland—might not differ much from 3000° C., since in the electric furnace at perhaps 3500° C. all known elements volatilize. I cannot share this view, but think that the temperature of the sun is higher, and probably as high as mentioned before, but, in spite of that, we may very well assume that *the bulk of the sun is in the liquid state.*

The temperature *in* the electric furnace must, without doubt, reach considerably higher than 3500° C., which is the generally admitted temperature of the electric arc in air.[1] Moissan considered this also as the minimum, for he said on this point, rather *too* cautiously, in his book *Der electrische Ofen* (German edition, Berlin, 1897, p. 25):

> Wir hatten aber immer den Eindruck bei zahlreichen, hierauf bezüglichen Untersuchungen, unter sehr verschiedenen Spannungen, *dass die Temperatur in dem Masse stieg, als die Leistungsfähigkeit der Maschinen, mit denen wir arbeiteten* [. . . . that the temperature rose in the same measure as the efficiency of the machinery at our disposal].

In his latest experiments Moissan had at his command an electric current equal to 300 horsepower, and this amount of energy was utilized for a time from 5 to 20 minutes to heat a clear space *in* the electric furnace of perhaps $13 \times 13 = 169$ cm. His largest crucibles measured 9 cm in diameter, and he says it were well to have still a free space of 2 cm between the crucible and the sides of the furnace. The supplied energy of 300 HP for about 169 cm equals about 18,000 HP for one square meter, whereas the sun's radiation from one square meter at the solar surface is calculated to equal 130,000 HP.[2]

[1] Lummer and Pringsheim found this temperature to be from 3500° to 4200° C.

[2] Young, *Manual*, p. 251.

This proportion corresponds to a temperature of about 3500° C. for the electric furnace, and of about 5400° C. for the sun, and further to the supposition that the heat generated is freely dissipated by radiation in the surrounding space. If, however, to a certain space, such as the interior of the electric-furnace, energy is continuously supplied for some time, and this energy cannot dissipate by radiation, and likewise not by conduction (which Moissan tells us), then necessarily the temperature in the interior of the furnace must increase, until the increase is checked by the melting and evaporation of the limestone of which the furnace is constructed. Therefore I think that we are well justified in supposing *that the temperatures attainable in a Moissan electric furnace are comparable to the sun's temperature, as we know it today.*

Now Moissan has shown that even at the enormous temperatures attained in his electric furnace, we have not yet reached the point at which all terrestrial elements are truly boiling. In this respect the following table is very instructive, which Moissan gave in *Comptes Rendus* of February 19, 1906 (**142**, 430). I quote Moissan's own words as follows:

Nos principales expériences sont résumées dans le tableau suivant, qui montre bien la différence des points d'ébullition des métaux de la famille du fer:

Métal	Poids: grammes	Temps, minutes	Ampères	Volts	Métal distillé, grammes
Nickel	150	5	500	110	56
	200	9	500	100	200
Fer	150	5	500	110	14
	825	10	1000	55	150
	800	20	1000	110	400
Manganèse	150	3	500	110	38
	150	5	500	110	80
Chrome	150	5	500	110	38
Molybdène	150	10	700	110	0
	150	20	700	110	56
Tungstène (Wolfram)	150	20	800	110	25
Uranium	150	5	500	110	0
	150	5	700	110	15
	200	9	900	110	200

Moissan further adds the following remarks:

Molybdenum. The 150 gr were not fused by a current of 500 amperes and 110 volts. After applying 700 amperes and 110 volts for 7 minutes, the metal was fused, but nothing evaporated. After 20 minutes 56 gr were distilled.

Tungsten (Wolfram). After applying 500 amperes and 110 volts for 5 minutes, the metal was not yet fused. After applying 800 amperes and 110 volts for 20 minutes, boiling commenced, but only 25 gr distilled.

Another highly interesting paper of Moissan is: "Sur la distillation des corps simples."[1] We here find the following statement:

> Gold commences to evaporate *in vacuo* at 1070°;
> it boils *in vacuo* at 1800°;
> and should boil at 760 mm pressure at 2530°;

thus showing how much depends upon the pressure under which the boiling takes place. Now all Moissan's experiments, tabulated above, are made at ordinary atmospheric pressure, and we are entirely at a loss to say how much the evaporation of the various metals would have been retarded under increased pressure, such as we may expect at the very base of the solar atmosphere, close to the liquid nucleus.

Moissan tried also the metalloid *titanium* in his electric furnace. Five hundred gr were heated by a current of 500 amp. and 110 volts; after 4 minutes vapor appeared, but after 5 minutes the stuff was fused only on the surface, and carbide of titanium had formed. Then 300 gr were treated with 1000 amp. and 55 volts for 7 minutes; 110 gr were distilled; the stuff itself, however, had been only viscous, the surface had not become horizontal. In his book *Der electrische Ofen*, p. 238, he says that even with a current of 2200 amperes and 60 volts the stuff in the crucible is not completely fused.

The conclusion which we must draw from Moissan's investigations and experiments is, therefore, that it is a grave error to consider the sun as a completely gaseous body, as it was considered for a long time but erroneously, because at relatively low temperatures all terrestrial elements and compounds were not only molten, but totally evaporated and entirely dissociated. Moissan has shown that such views are incorrect.

The fact that we observe iron-vapor in the atmosphere outside the photosphere does not exclude the possibility that this element could

[1] *Annales de Chimie et de Physique* (8), **8**, 145–181, 1906.

exist in lower, thus hotter, levels, still in the *liquid* state. Aqueous vapor exists in the earth's atmosphere up to altitudes of 70 to 80 km where the temperatures must be far lower than −100° C. An astrophysicist, say on the moon, who would therefrom draw the conclusion that liquid water, or solid ice, could not exist at the base of the earth's atmosphere, would, of course, be greatly mistaken.

Professor A Ritter, who during the period 1880 to 1889 published in *Wiedemann's Annalen* a series of articles on "Die Constitution gasförmiger Weltkörper," says (**36**, 567, 1889) at the beginning of the closing section 19 (when he had read my paper in *Astronomische Nachrichten*, Nos. 2847, 2848, 1888):

> Die Hypothese des *gasförmigen* Zustandes der Sonne müsste dagegen zur *zweiten* Gruppe—welche bei voller Anerkennung ihrer Unzuverlässigkeit, *nur versuchsweise* aufgestellt wurden—gerechnet werden; *denn niemand ist im Stande, zuverlässige Auskunft darüber zu geben, wie das Innere der Sonnenmasse beschaffen ist.*

It is generally claimed for the theory of the entirely gaseous nature of all self-luminous stars, that only this state affords the possibility of the constancy of radiation. A liquid star, it is said, would be covered rapidly by a non-luminous crust. This, however, is not correct under all circumstances. At the high temperature of the sun, its liquid masses must be very fluid, quite in contrast to gases, which are probably of greater viscosity at high temperatures. Thus we are justified in assuming very entensive convection-currents in the cooling, liquid sun, provided the bulk of the same consists of material of uniform density. As further the Helmholtz contraction-hypothesis holds as well for the liquid as for the gaseous state, we find that the latter state is in no way superior to the liquid state concerning the maintenance of solar radiation.

As pointed out, it is only necessary for my hypothesis that the sun—or a similar star—to a depth of perhaps half the radius be of uniform density, whereas the remaining innermost nucleus may contain masses of greater density. If this condition is not fulfilled, and the outer layer of least density is relatively thin, then this layer will cool down rapidly, and the star will be covered really by a non-luminous crust. This would explain the fact that in some binaries one of the components, in spite of a considerable mass, may be of far less

brilliancy, or even quite dark, as compared with the other component. If the outer, dark layer is incomplete, or very thin, so that it may be broken up at times, this would afford an explanation of the wide, irregular range in brilliancy of certain variables.

These are the chief reasons for which I hold that the sun, including, perhaps, most other stars, is not entirely gaseous, but only *in the liquid state*, as assumed by Kirchhoff and Zöllner, a state which enables us also to explain all solar phenomena upon generally recognized physical principles

HAMBURG
1908

INTERACTION OF SUN-SPOTS

By PHILIP FOX and GIORGIO ABETTI

If a review be made of the records of sun-spot positions, considering the spots individually and regarding especially their longitude, a seeming interrelation of the spots of the two hemispheres appears, for they will be found not infrequently to travel in pairs, paralleling each other on opposite sides of the equator. To decide whether there is a physical foundation for this coincidence in longitude, or whether the coincidence is due to chance, would require, in the absence of an actual, visible demonstration of interaction, an extended statistical study.

An examination of the sun-spot charts of Carrington[1] and of Spoerer[2] indicates the number of coincidences to be about equal to the probability of coincidence from chance arrangement. We counted the coincidences on Spoerer's charts, regarding spots as coincident when some part of either group was between the meridians bounding its neighbor, and found 28 per cent. of the spots traveling in pairs. The average length in longitude of a group is 5°.66. The space allowed for coincidence on the average is then 17°.0. The average number of spot groups per revolution was 11.27, which gives for the average space occupied by each spot in each hemisphere 64°.0. The probability of coincidence is then $17.0 \div 64.0 = 26.5$ per cent. We cannot affirm from this test that a spot in one hemisphere tends in general to accompany a spot in the opposite hemisphere.

We have also examined the Rumford spectroheliograms, counting not only coincidences of spots with spots but of spots with disturbances indicated by flocculi. This test yielded a percentage of coincidences somewhat larger than the probability would call for.

However the general case may stand, in certain individual cases a physical connection seems evident. Concerning this, Maunder states:[3] "Nothing is more striking in the case of a considerable disturbance

[1] *Observations of Solar Spots.*

[2] *Publicationen der Astronomischen Gesellschaft*, 13; *Publicationen des Astrophysikalischen Observatoriums zu Potsdam*, 1, 2, 4, and 10.

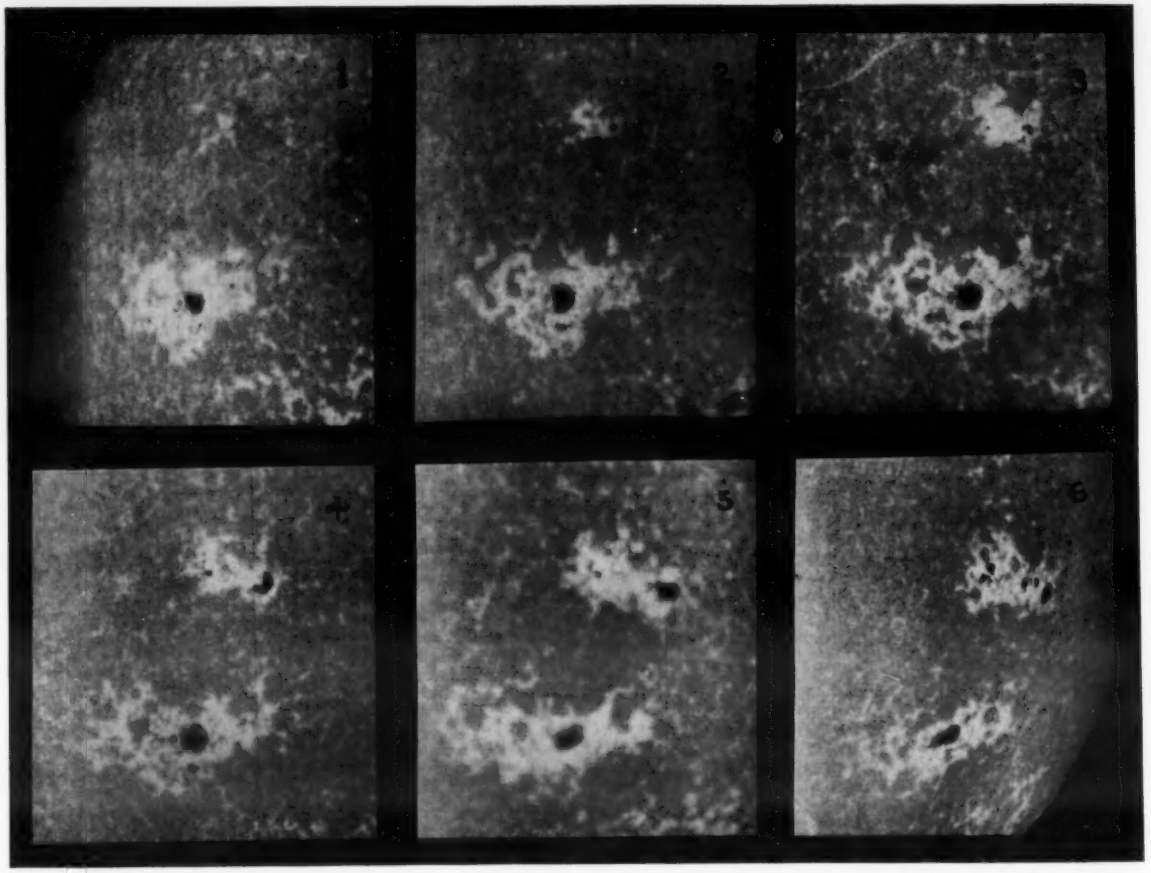
[3] *Knowledge*, 17, 199, 1894.

PLATE I

N

May 6, $3^h\ 40^m$ G. M. T. May 7, $3^h\ 37^m$ May 8, $3^h\ 23^m$

E



W

May 9, $3^h\ 10^m$ May 11, $4^h\ 19^m$ May 13, $4^h\ 19^m$

SPECTROHELIOGRAMS SHOWING DEVELOPMENT OF COMPANION SPOT
May 1907. Scale: Sun's Diameter=150 mm

than to see it repeat itself, at it were, in another latitude, and an active train will often be accompanied by a feebler copy of itself a few degrees north or south." This is well illustrated on Spoerer's charts for the revolutions Nos. 32 and 43, also in Plates XIX and XX (**28,** 256, 1908) of this *Journal.* Plate I, made from Rumford spectroheliograms of May 1907, shows the development of a spot, Greenwich No. 6185, as a northern companion of a southern spot here making its second appearance on the disk, Greenwich No. 6184. The plate needs no further explanation than the appended data supplies, except to point out that the coming spot was, as usual, antedated by the flocculus.[1] The east limb is seen on the photograph of May 6 and the west on the plate of May 13, the spots having nearly crossed the disk.

As the spots approach the equator toward the end of the sun-spot maximum and the distance between north and south neighbors lessens, it seemed hopeful that if there was communication between them, perhaps normally confined to action below the surface, some visible demonstration of connection might be observed upon the surface. Fortunately on September 10 we obtained a series of plates with the Rumford spectroheliograph showing positive proof of such interaction. Certain of these plates illustrating the various stages of the events are reproduced in Plates II and III. Figs. 2 and 11 are from calcium (H line) spectroheliograms, the others are hydrogen with the line *Ha*, using "pan-iso" plates.

The spots concerned were the pair, lying in opposite hemispheres, which were near the center of the disk on September 9, 1908. A study of the plates on previous days revealed no unusual features. The southern spot was first seen on August 8 as a small spot near the east limb. On August 10 it had disappeared but was again present on August 13. From this date it developed rapidly. The northern spot was first seen on the plates of August 13. It too died out but was again present and rapidly developing when the region came into view on the east limb on September 4. On September 8 and 9 spots were present in the isolated flocculus preceding the northern spot.[2]

The appearance of the groups on September 9 is shown in Fig. 1

[1] Fox, *Astrophysical Journal,* **28,** 255, 1908.

[2] Hale, *Astrophysical Journal,* **28,** 323, Plate XXVII, 1908.

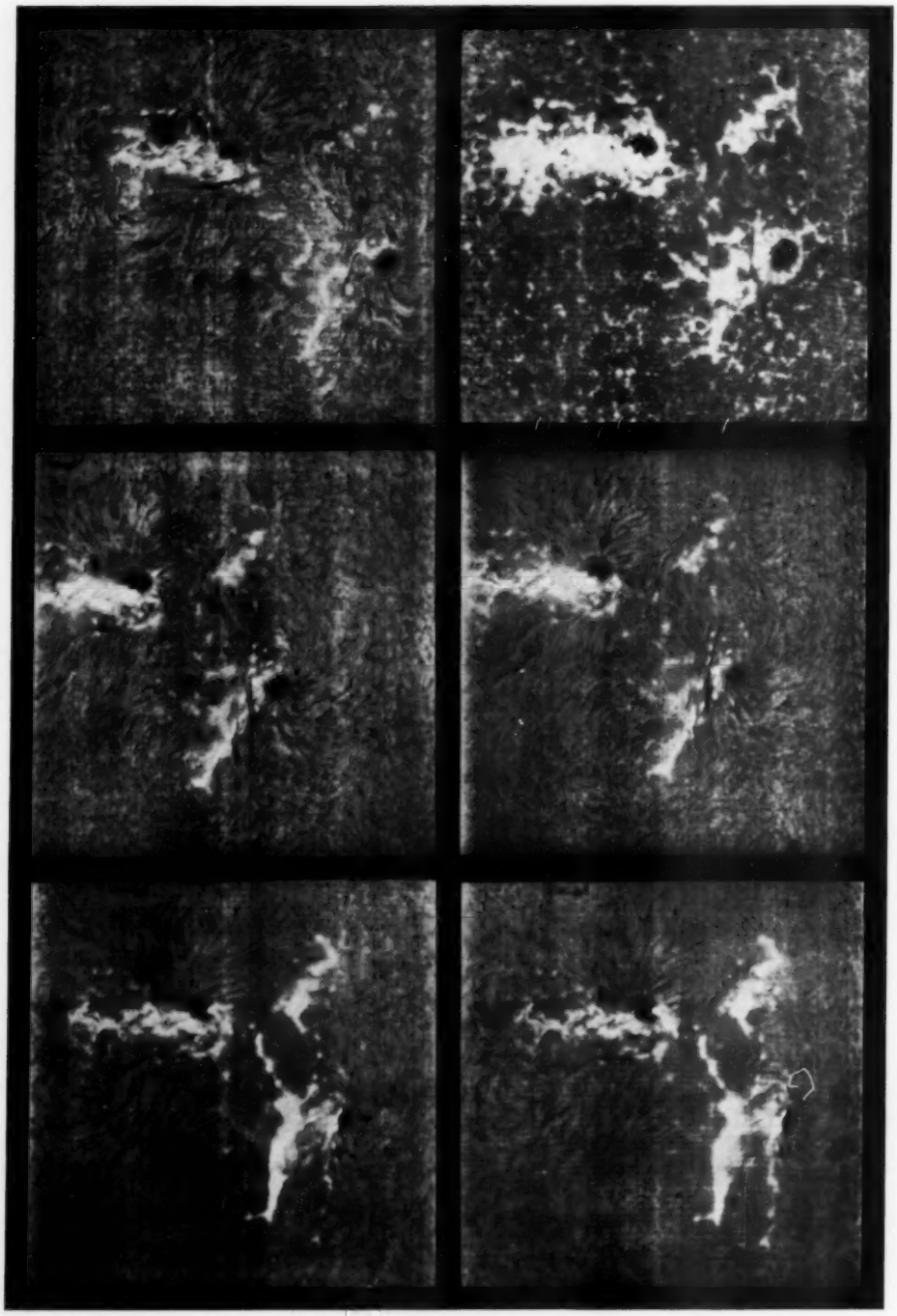
of Plate II. The first plates of September 10 were the routine calcium exposures, Fig. 2. These showed considerable activity in the spot groups, principally in the eruptions in the northern group. The *Hα* plates of $5^h\ 36^m$ and $5^h\ 58^m$ G. M. T. revealed an intensification of the eruptions in the northern group,[1] a brightening of the flocculi following the southern group, and a slight strengthening of the isolated flocculus preceding the northern group, but gave no intimation of the pending outburst. Visual, spectroscopic examination at $7^h\ 30^m$ G. M. T. indicated a violent uprush of hydrogen immediately behind the southern spot and also at some distance following. A plate was immediately exposed, $7^h\ 52^m$. On this and subsequent plates tremendous changes were found. A brilliant eruption had occurred behind and in contact with the southern spot. Somewhat more remotely following, a still greater and more striking eruption was in progress, extending east and south like a great leg, brilliant to its toe, and stretching to the north in two branches, one nearly to the neighboring spot, the other a chain of brilliant eruptions reaching toward the isolated flocculus. This flocculus, the remains of an expired spot, had increased greatly in intensity and had extended arms toward the approaching chain of eruptions and toward the northern spot. From the northern spot an eruptive arm stretched to meet the eruptions advancing from below and from the flocculus. This is well seen at $8^h\ 13^m$. At $8^h\ 25^m$ the connection of the northern and southern spots was completed.

After this consummation the subsidence to relative tranquillity was as rapid as the rise. Examination of the line *Hα* at $9^h\ 30^m$ revealed descent in the eruptive regions behind the southern spot. Measurement of the displacement of the line on the photographs made at this time gives velocity of descent behind the spot as about 100 km per second and 170 km in the great eruption due east of the spot. The result of this is seen on the plates at $9^h\ 39^m$ and $9^h\ 48^m$ in the obliteration of the eruptive feature behind the spot and in the decline in the great eruption. Other plates exposed later showed a continued decline. The whole display lasted less than four hours and fortunately the history of it as shown on our plates is nearly complete.

[1] Dennett observed an eruption in this group on September 9 lasting from 19^h45 to 20^h30 G. M. T. *Observatory*, **31**, 388, 1908.

PLATE II

N



Sept. 9
$7^h\,56^m.0$
Ha

Sept. 10
$3^h\,39^m.2$
Ca H_2

Sept. 10
E $5^h\,36^m.5$
Ha

Sept. 10
$5^h\,58^m.0$ W
Ha

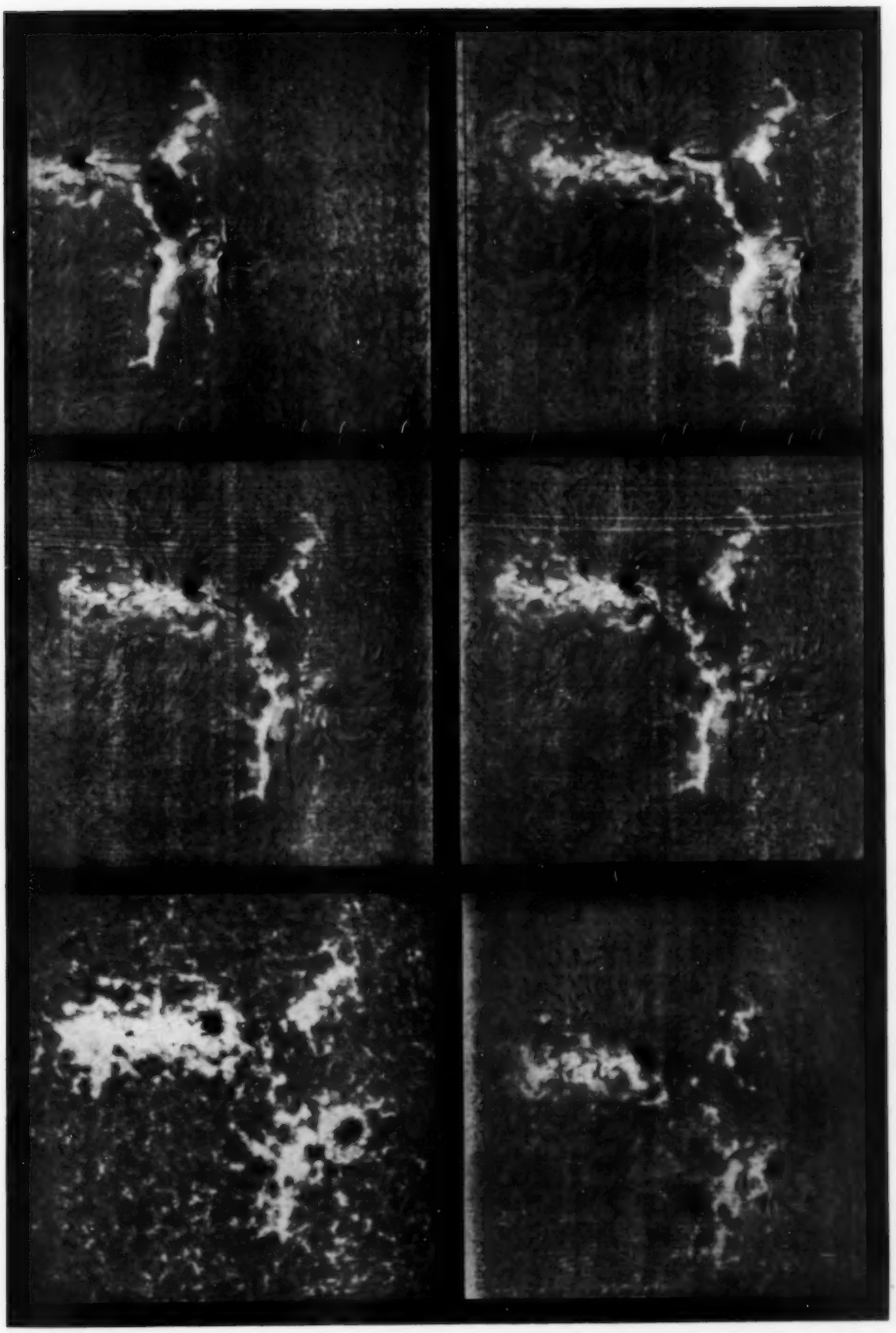
Sept. 10
$7^h\,52^m.4$
Ha

Sept. 10
$8^h\,2^m.7$
Ha

ERUPTION CONNECTING SUN-SPOTS
September 9–10, 1908. Scale: Sun's Diameter=150 mm

PLATE III

N



Sept. 10
$8^h\,16^m5$
Ha

Sept. 10
$8^h\,25^m5$
Ha

Sept. 10
E $9^h\,39^m1$
Ha

Sept. 10
$9^h\,48^m5$ W
Ha

Sept. 10
$10^h\,50^m8$
Ca H_2

Sept. 11
$4^h\,19^m0$
Ha

ERUPTION CONNECTING SUN-SPOTS
September 10–11, 1908. Scale: Sun's Diameter = 150 mm

It is to be regretted that we obtained no calcium plate when the disturbance was at its height. A plate at $10^h\ 51^m$ furnishes no startling changes when compared with the calcium plate at $3^h\ 39^m$. Certain minor changes, visible in the arrangement of the flocculi between the spots, are of such character (the chain, for example, is nearly continuous), that there seems little room to doubt that the calcium fully participated in the disturbance. Intensification in the eruptions following the northern spot is also noticeable. On the following day many small spots had developed in the flocculi train. An *Ha* plate of September 11 is added to show the return to a more quiet existence.

The further history of these groups, so far as we have observed, was uneventful. Only one thing need be mentioned. On the next return of the spots to the center of the disk the space between the two groups as shown on the calcium plates was filled with small scattered flocculi.

The heliographic positions of the spots of the groups and of the flocculi about them were measured on plates before and after September 10 to determine if any notable drifts occurred. We reduced the plates using the constants employed at Greenwich. The positions of the leader spots are collected in the accompanying table. Between September 8 and 12 the southern spot remained unmoved in its position, but it is perhaps significant that the northern spot had advanced toward the southern 3°.3 in longitude and 1°.7 in latitude. The flocculi showed no consistent motions either of translation or rotation.

Hale has pointed out[1] the resemblance of the pattern made by the hydrogen flocculi and that of iron filings in a magnetic field. It is of interest, though of doubtful significance, that the hydrogen flocculi following the northern spot group have the heart-shaped configuration of the lines behind the weaker of two interacting electrical masses of unlike sign. We have considered the possibility of explaining this configuration as a section through an inclined vortex but this necessitates assigning far too great depth to the vortices. An indraught from the rear along the line of brilliant flocculi following the spot would be a sufficient, though perhaps not probable, mechanical explanation.

[1] *Astrophysical Journal*, **28**, 114, 1908.

Several investigators have expressed the opinion that the source of terrestrial magnetic storms is in the eruptions about the spots rather than in the spots themselves. Hale in discussing the magnetic fields which he has recently detected in sun-spots concludes, from the rapid diminution of strength of field with altitude, that terrestrial magnetic storms are probably not caused directly by these fields[1] and

Plate No.	Date	G. M. T.	North Spot		South Spot		North Spot—South Spot	
			Heliographic Long.	Heliographic Lat.	Heliographic Long.	Heliographic Lat.	Long.	Lat.
	1908							
Σs 2949...	Aug. 13	4h 2m.2	265°.1	+11°.7	272°.1	−4°.3	+ 7°.0	+16°.0*
2955...	Aug. 14	5 48.2	266.9	+11.8	274.3	−5.0	+ 7.4	+16.8†
3057...	Sept. 8	4 37.2	267.2	+12.9	280.0	−5.6	+12.8	+18.5‡
3059...	Sept. 8	4 55.0	267.1	+12.8	279.7	−5.7	+12.6	+18.5
3063...	Sept. 9	4 40.5	268.7	+11.7	280.0	−5.6	+11.3	+17.3
3069...	Sept. 10	3 39.2	269.9	+11.3	279.7	−5.7	+ 9.8	+17.0¶
3071...	Sept. 10	3 56.1	270.1	+11.4	279.9	−5.6	+ 9.8	+17.0¶
3080...	Sept. 10	10 45.3	270.3	+11.4	279.7	−5.3	+ 9.4	+16.7
3082...	Sept. 11	2 24.5	270.7	+11.3	279.9	−5.6	+ 9.2	+16.9
3084...	Sept. 11	2 40.8	270.6	+11.1	279.9	−5.6	+ 9.3	+16.7§
3091...	Sept. 12	4 41.3	270.5	+11.1	280.0	−5.8	+ 9.5	+16.9
3141...	Oct. 2	3 37.4	271.5	+11.5	278.1	−5.5	+ 6.6	+17.0**
Σy 520...	Oct. 2	9 10.7	271.6	+11.8	278.1	−5.4	+ 6.5	+17.2
Σs 3153...	Oct. 5	3 53.2	271.7	+12.0	278.5	−5.4	+ 6.8	+17.4
3170...	Oct. 10	3 32.4	271.6	+12.5	280.3	−4.6	+ 8.7	+17.1

* First rotation.—The north spot is the leader of an oval group.

† South spot scarcely visible. ‡ Second rotation. ¶ Bridge across the north spot.

§ Many new spots in the train following the north spot. ** Third rotation.

REMARKS

Measurements are for the leader spot.

The plate Σy 520 is a direct photograph with the 40-inch, all others (Σs) are calcium spectroheliograms.

states: "Their origin may be sought with more hope of success in the eruptions shown on spectroheliograph plates in the regions surrounding spots." A disturbance of the magnitude of this one of September 10 might have been expected to produce noticeable effects on the earth. In *Nature* of September 24 Chree describes a large magnetic storm which occurred on September 11, beginning at $9^h\ 47^m$. The lag in

[1] *Astrophysical Journal*, **28**, 341, 1908; see also Schuster, *Nature*, **78**, 663, 1908; *M. N.*, **65**, 187, 1904.

time between the solar and terrestrial storms, something over twenty-six hours, is not consistent with the view of Young[1] and of Nordmann[2] that the magnetic impulse travels with the speed of light; but is more in harmony with the observations of Maunder[3] and of Riccò,[4] who find retardations of 26^h and $45^h.5$ respectively. The lags found by Maunder and Riccò, though both rest on the central meridian passage of sun-spots, are not directly comparable, for Maunder determined the lag to the middle of the magnetic storm and Riccò to the maximum.

In conclusion we express our indebtedness to Mr. Wallace for his instruction in the preparation and manipulation of the pan-iso plates.

YERKES OBSERVATORY
November 10, 1908

[1] *Nature*, **7**, 109, 1872.

[2] *Journal de Physique* (4), **3**, 115 1904.

[3] *Monthly Notices*, **64**, 207, 1903–1904.

[4] *Memorie Spet. Ital.*, **33**, 38, 1904.

ON THE ABSORPTION OF LIGHT IN SPACE[1]

By J. C. KAPTEYN[2]

Undoubtedly one of the greatest difficulties, if not the greatest of all, in the way of obtaining an understanding of the real distribution of the stars in space, lies in our uncertainty about the amount of loss suffered by the light of the stars on its way to the observer. For the sake of brevity and in accordance with what has been done by other astronomers, I will designate this loss by the name of *absorption* of light, though the loss caused by *scattering* of light will be included.

Elsewhere (*Astronomical Journal*, No. 566, **24**, 115, 1904) I tried to show how fundamentally our results for the arrangement of the stars in space are changed by admitting even an absorption of light considered as small by some astronomers.

Now there can be little doubt, in my opinion, about the existence of absorption in space and I think that even a good guess as to the order of its amount can be made. For, first, we know that space contains an enormous mass of meteoric matter. This matter must necessarily intercept some part of the star-light.

In the second place, if, assuming the universe to be completely transparent, we apply the method explained in *Publications of the Groningen Laboratory*, No. 11, we find that the stars gradually thin out as we recede farther and farther from the sun. In *Astronomical Journal*, No. 566, I showed that the data used in this investigation are about as well represented if we assume that the star-density is the same at different distances from the sun, provided that we introduce an absorption of light of a determined small amount.

The choice between the two probabilities does not seem to be very difficult. For the data brought together in *Publications of the Groningen Laboratory*, No. 18, show that there is little difference in the distribution of the stars over the different magnitudes in diametrically opposite regions of the sky.

[1] *Contributions from the Mount Wilson Solar Observatory*, No. 31.

[2] Research Associate of the Mount Wilson Solar Observatory.

From this we may conclude that, if there is a thinning-out of the stars for increasing distance from the sun, it must be so in whatever direction from the sun we proceed.[1] This would assign to our sun a very exceptional place in the stellar system, viz., the place of maximum density.

On the other hand, if we assume that the thinning-out of the stars is simply apparent and due to absorption of light, the apparent thinning-out in any arbitrary direction is perfectly natural.

The latter alternative is therefore undoubtedly the most probable one, and as there is, at least for every zone of galactic latitude, only one value (a) of the amount of absorption which would lead to a nearly constant density, whereas a greater amount would lead to the result that the star-density would *increase* on all sides of the sun (that is, would lead to the same difficulty as before), it would seem probable that the amount of absorption must be of the order a.

In *Astronomical Journal*, No. 566, I found for a the value of 0.016 magnitude for a distance of 33 light-years (corresponding to a parallax of 0″.1) as an average for the whole of the sky. Using better material,[2] the result will doubtlessly be somewhat different. It is hardly necessary to say that I do not propose a value obtained in this way for acceptance. The method is by no means fundamental. I merely think that there is some reason to believe that the average absorption must be of this *order of magnitude*.

In the same paper I proposed a more fundamental method for the derivation of the absorption. The data in existence at the time, however, proved to be still inadequate. I have now collected far more extensive material which must lead to a considerable improvement. The plan of selected areas will, in due time, furnish still better data. Elsewhere I suggested another independent way of determining the absorption by extended observation of nebulae.[3]

[1] The proof is not complete because different galactic latitudes were not separately treated. I have, however, convinced myself, in a rough way, that thinning-out of the stars is found for every zone of galactic latitude. This, together with the fact that the distribution of the stars varies very little with the galactic longitude, proves our conclusion.

[2] A beginning has been made in *Proceedings of the Academy of Science at Amsterdam*, 1908, p. 626.

[3] *Plan of Selected Areas*, p. 57.

Meanwhile it cannot be denied that the truly fundamental importance of the absorption of light makes it highly desirable to find still other methods, depending on quite different data. Such a new method could probably be obtained if it turns out that the absorption in interstellar space is more or less *selective*. If the absorption and scattering of light by meteoric matter is really sensible, then there can be no reasonable doubt but that the violet end of the spectrum must be more strongly affected than the less refrangible rays.

But even the probability of gas-absorption, producing absorption lines or bands in the spectrum, cannot be denied a priori. Owing to the gas of the corona lost by the sun, to similar loss presumably suffered by the other stars, to that lost by comets, etc., interstellar space must contain, at every moment, a considerable amount of gas. Might not this gas, in a thickness of hundreds of light-years, cause an appreciable absorption of light?

It thus seems that there is reason to inquire whether or not light suffers in space (*a*) a general absorption, particularly strong in the violet; (*b*) a selective absorption, widening or strengthening lines or bands in the spectrum.

To my regret I have never had the opportunity of undertaking the observations necessary to settle these questions. Recently, however, I obtained some results from the Harvard observations, which can be explained most readily by an absorption of the first kind.

In the observations of the spectra of the bright stars (*Harvard Annals*, **28**, Part I) Miss Maury distinguishes, in Class XV*a*, two divisions. One of these has the remark 184, the other the remark 185. The parts of these remarks to which I wish to call attention are as follows:

"184. This star resembles *α Bootis* in the absorption shown in the region having wave-length shorter than 4307."

"185. This star resembles *α Cassiopeiae* in the general absorption shown in the region having wave-length shorter than 4307."

In the detailed description of the classification (p. 39) the difference is described in these words:

> The stars of this group (XV*a*) appear to fall into two divisions, exhibiting a slight difference in the degree of general absorption in the violet regions. Of these divisions *α Bootis* and *α Cassiopeiae* are respectively typical. In the first

the general absorption is slight; in the second, it is more conspicuous both in the regions of the violet above mentioned and beyond wave-length 3889, where the photographic spectrum generally appears to be suddenly cut off.

The distinction here made is a very difficult one in practice, owing to the fact that different photographs of the *same* stars show considerable difference in the general absorption of the violet. The difficulty is so great that Miss Cannon, in the classification of the southern stars, gave up this division altogether. She says (*Harvard Annals*, **28**, Part II, p. 159), "These effects were found to vary so much in different photographs of the same star taken under different conditions that they have been assumed to be photographic effects, rather than real."

On the other hand, Miss Maury contends (*ibid.*, Part I, p. 39), "The degree of absorption indicated also varies in photographs of different density so that, *while there seems to be sufficient ground for believing that the distinction is a real one, there is more or less liability to error in assigning individual stars to one or the other division.*"

I have taken the liberty of italicizing the words which, in order to appreciate what follows, we must keep well in mind. I have been led to think, with Miss Maury, *that the distinction is probably a real one* and that the most natural, though not the only way to account for it is to attribute it to *space-absorption*.

The suspicion that it might be due to space-absorption was of course at once raised by the preceding considerations. It is easy to see how it may be tested.

If it is well founded, then the stars belonging to the *α Cassiopeiae* division must be farther removed from the solar system than the stars of the *α Bootis* division. Our knowledge about individual parallaxes is far too defective to be of any use in the present question. In the absence of the parallaxes the amount of proper motion will be the safest guide in our estimate of the evidence. If our suspicion is in accord with nature, we have to expect that the stars in the *α Cassiopeiae* division will in general have smaller proper motions than the stars in the division of *α Bootis*.

The following summary shows the proper motions for all the stars in the two divisions. With very few exceptions they were taken from Newcomb's *Fundamental Catalogue*. Those which are not

contained in that catalogue were taken from Auwers-Bradley as corrected in *Groningen Publications*, No. 9. All the proper motions may thus be considered as being very reliable.

To the stars in Class XV*a* were added nine stars from Class XIV and *XIV* for which, according to the remarks of Miss Maury, the

α *CASSIOPEIAE* GROUP

No. in *H. P.*	Star	Mag. in *H. P.*	α 1900	δ 1900	Spectrum	Cent. P. M.
45	ι *Ceti*	3.6	0^h14^m	− 9°23′		3″
92	δ *Andromedae*	3.4	34	+30 19		17
94	α *Cassiopeiae*	2.2	35	+56 00		6
103	β *Ceti*	2.1	38	−18 32		23
122	*62 Piscium*	6.0	43	+ 6 45		7
155	*43 H Cephei*	4.5	55	+85 43		8
183	η *Ceti*	3.6	1 3	−10 43		25
220	θ *Ceti*	3.8	19	− 8 42		23
251	υ *Persei*	3.7	32	+48 07		13
333	α *Arietis*	2.0	2 2	+23 00		24
498	κ *Persei*	4.0	3 3	+44 29		23
560	σ *Persei*	4.4	24	+47 39		3
750	δ *Tauri*	4.0	4 17	+17 18		11
775	θ′ *Tauri*	3.9	23	+15 44		7
1452	*26 Monocerotis*	4.2	7 36	− 9 19		8
1453	σ *Geminorum*	4.1	37	+29 07		23
1629	ζ *Hydrae*	3.3	8 50	+ 6 19		9
1695	*1H Draconis*	4.6	9 23	+81 46	XV. *a*	3
1760	μ *Leonis*	4.1	47	+26 29		24
1800	λ *Hydrae*	3.9	10 6	−11 51		22
1902	*46 Leon. min.*	3.9	48	+34 45		30
2056	*14 H′ Draconis*	5.8	12 0	+77 28		16
2063	ε *Corvi*	3.1	5	−22 03		7
2208	ε *Virginis*	3.0	57	+11 30		27
2569	ι *Draconis*	3.3	15 23	+59 19		1
2627	α *Serpentis*	2.7	39	+ 6 44		14
2962	β *Ophiuchi*	2.9	17 38	+ 4 36		16
3003	ξ *Draconis*	3.9	52	+56 55		13
3007	ξ *Herculis*	3.9	54	+29 15		9
3084	δ *Sagittarii*	2.8	18 15	−29 52		5
3328	τ *Draconis*	4.5	19 17	+73 10		17
3519	*19 Vulpeculae*	5.8	20 8	+26 31		0
3732	ζ *Cygni*	3.5	21 9	+29 49		6
3836	ε *Pegasi*	2.4	39	+ 9 25		2
3923	ζ *Cephei*	3.5	22 7	+57 43		2
4182	γ *Cephei*	3.4	23 35	+77 04		17
994	β *Leporis*	3.0	5 24	−20 51	XIV. *a*	9
1312	o^1 *Canis majoris*	4.0	6 50	−24 04	*XIV. a*	4
1474	ξ *Argus*	3.4	7 45	−24 37	XIV. *P*	0
1747	ε *Leonis*	3.1	9 40	+24 14	XIV. *P*	5
2249	γ *Hydrae*	3.3	13 14	−22 39	*XIV. a*	8
2515	β *Bootis*	3.6	14 58	+40 47	*XIV. a*	6
3779	ζ *Capricorni*	3.8	21 21	−22 51	*XIV. P*	2
3780	*35 Capricorni*	6.0	21 22	−21 37	*XIV. a*	6
4020	η *Pegasi*	3.1	22 38	+29 42	XIV. *a*	4

α *BOOTIS* GROUP

No. in *H. P.*	Star	Mag. in *H. P.*	α 1900	δ 1900	Spectrum	Cent. P. M.
..	*54 Piscium*	6.1	0^h34^m	+20°43′		60″
93	*55 Piscium*	5.5	35	+20 54		3
812	*53 Eridani*	3.9	4 34	−14 30		18
1086	*δ Leporis*	4.0	5 47	−20 54		69
1093	*δ Aurigae*	3.8	51	+54 17		16
1459	*β Geminorum*	1.1	7 39	+28 16		62
1823	*γ Leonis*	2.2	10 14	+20 21		34
1926	*α Urs. maj.*	2.0	58	+62 18		14
1961	*ν Urs. maj.*	3.8	11 13	+33 39		4
1963	*δ Crateris*	3.9	14	−14 14		23
1999	*2 Draconis*	5.5	30	+69 52		16
2400	*α Bootis*	0.0	14 11	+19 44		228
2541	*δ Bootis*	3.5	15 12	+33 42	XV. *a*	16
2589	*γ Librae*	4.0	30	−14 27		7
2736	*ε Ophiuchi*	3.4	16 13	− 4 27		9
2774	*β Herculis*	2.8	26	+21 42		11
3037	*70 Ophiuchi*	4.1	18 00	+ 2 32		115
3090	*η Serpentis*	3.4	16	− 2 56		90
3447	*ε Draconis*	3.9	19 48	+70 01		9
3450	*β Aquilae*	4.0	50	+ 6 10		48
3648	*ε Cygni*	2.7	20 42	+33 36		49
3656	*η Cephei*	3.6	43	+61 26		83
4034	*μ Pegasi*	3.7	22 45	+24 05		16
4114	*γ Piscium*	3.8	23 12	+ 2 44		75
4174	*λ Andromedae*	3.9	33	+45 56		45

absorption for wave-lengths below 3889 approaches that of *α Cassiopeiae*.

From this summary we see that neither are the proper motions of the stars in the *α Cassiopeiae* division exclusively small, nor the motions of the *α Bootis* stars invariably considerable. After the words quoted from both Miss Cannon and Miss Maury such a thing could not be expected. Moreover, at least some of the proper motions of the *α Bootis* stars may only *appear* to be small because they are seen strongly foreshortened, and at least a few of the proper motions of the *α Cassiopeiae* stars must be large, *not* owing to small distance, but in consequence of an exceptionally large linear velocity. Finally, in classifying the stars into two divisions gradually merging into one another, there must always be a certain proportion so near the line of division that they might almost equally well be put in either class. In this respect it is worthy of notice that for Class XIV Miss Maury made no division on account of absorption in the violet. For this class we may thus presume that she will have drawn attention *only*

to the well-marked cases. For this reason the fact that in *all* these cases, without exception, the proper motion is small seems very significant. Notwithstanding the contrary cases, our list shows clearly that, *as a rule*, the proper motions in the *α Bootis* division exceed those in the other group very considerably.

The following averages may show this yet more forcibly.

		α Cassiopeiae div.	*α Bootis* div.
General mean of centennial motion.....		11".4 (45 stars)	47".1 (25 stars)
Partial means	$\alpha = 0^h$ to $\alpha = 6^h$.....	13.6 (15 stars)	33.0 (5 stars)
	6 to 12	12.9 (10 stars)	25.4 (6 stars)
	12 to 18	11.9 (10 stars)	54.1 (6 stars)
	18 to 24	6.1 (10 stars)	58.9 (9 stars)
Number of stars with centennial p.m. $< 10''$		58 per cent.	20 per cent.
Number of stars with centennial p.m. $> 30''$		0 per cent.	48 per cent.

The percentages become still more favorable to our supposition if we include only the cases in which two or more, or three or more plates have been taken. As the number of stars becomes rather small in these cases I will not further insist on this point.

The objection which might be based on the fact that the subdivision here discussed was made only in the case of Class XV*a*, whereas, if the interpretation by space-absorption is correct, it must show in all classes, loses greatly in force by the fact that all other classes of Miss Maury contain so small a number of stars that the contrast between the two divisions had small chance of being noticed.

If we grant the reality of the difference in the distance of the stars of the *α Bootis* and *α Cassiopeiae* divisions, it does not necessarily follow that the interpretation of the difference in the spectrum as being due to space-absorption must be correct. For, as the average magnitude of the stars in the two divisions is about the same, the total light-power (luminosity) of the more remote *α Cassiopeiae* stars must be greater than that of the *α Bootis* stars. The meaning of our result may therefore also be: for stars of the same spectrum, the light of the more luminous objects is relatively weaker in the violet part of the spectrum. Whichever view we think the more probable, the phenomenon seems well worthy of being more closely and carefully investigated.

Of course care will be taken to make the spectra to be compared

as equal as possible in the less refrangible part. Moreover, we shall choose exclusively extreme cases in regard to proper motion. In particular, fainter stars ought to be included in order that we may have a more extensive choice of stars having large proper motions and at the same time a larger difference of distance of the two groups to be compared. It seems unnecessary to enter into further details on this point. But a few lines may perhaps be allowable in order to show the importance of a determination of the space-absorption which might eventually result from such an investigation.

There is first, of course, the contribution we may expect for the determination of the *total* amount of absorption (the absorption-*constant* in the case the universe is fairly uniformly filled with the absorbing matter). As was pointed out above, such a determination would probably enable us to get rid of the main obstacle in the way of a reliable determination of the real distribution of stars in space. Then there is the fact that we shall get a *criterion* or even a *measure* of distance, which promises to be of particular value where other means begin to fail. To see this clearly we have only to consider how uncertain our determinations of average parallaxes, even if obtained by means of the parallactic motion, become for stars for which the distance exceeds, say, 3000 light-years. In the present state of science the discrimination between a distance of 3000 and a distance of 6000 light-years must be considered as practically impossible. On the contrary, if space is somewhat uniformly filled with matter, the difference between the absorption for the two classes of stars must be equal to that between stars at the respective distance zero and 3000 light-years.

Further, there is the importance of getting an insight into the true spectrum of the stars, freed from the changes brought about by the medium traversed by light on its way to the observer. Thus, for instance, is it not possible that the somewhat strange phenomenon, that, according to Huggins, stars of Secchi's second type often show spectra which, in the more refrangible part, are more intense and more extensive than in the spectra of the first type, is simply due to space-absorption? For it is well known that the average distance of the stars of the second type is considerably smaller than that of the stars of the first type of equal magnitude.

Even more important than the general absorption here discussed would be a gas-absorption, producing *space-lines* or *space-bands*. Indications of such an absorption might be obtained as above by comparing stars having spectra of the same class but of widely different proper motion. There would be, however, a decisive criterion by which we might prove or disprove the reality of our results. If there are space-lines, they must not share in that part of the radial motion which is due to the motion of the stars themselves. The space-lines must thus show their nature in somewhat the same way as the atmospheric lines of the solar spectrum in Cornu's well-known experiment.

As, however, I have no evidence as to the real occurrence of such lines or bands, no more need be said about them at present. I am permitted to say in conclusion, that in the program of the stellar work for the five-foot reflector of the Mount Wilson Solar Observatory some stars chosen with special reference to the subject of the present paper will be included.

MOUNT WILSON SOLAR OBSERVATORY
October 1908

SPECTRUM OF COMET MOREHOUSE (1908 *c*)

By EDWIN B. FROST and J. A. PARKHURST

Our intention to study this spectrum with the Zeiss doublet and objective-prism was put into effect on October 28. The ease with which a strong impression was obtained on a photographic plate showed that we might have begun observations considerably earlier, when the comet was much less bright. At that date an exposure of fifteen minutes was adequate to give distinctly the spectrum of the head as a row of seven knots. With an exposure of half an hour most of these extended out into the tail for at least 3°. On many of the later exposures the images of the tail ran off the plate, the edge of which was 3°.5 from the head.

The scale of the spectrum is exceedingly small, as the focal length of the objective is only 81.4 cm (aperture 14.5 cm) and the prism has an angle of but 15°. The distance from $H\beta$ (λ 4861) to $H\theta$ (λ 3798) in a stellar spectrum is only 3.0 mm, whence it is evident that but a slight degree of accuracy can be expected in the determination of wave-lengths. All the optical parts are of the ultra-violet ("U.V.") glass of Schott & Co., so that the transparency is excellent for the more refrangible portions of the spectrum.

Twenty-one satisfactory plates were obtained with the objective-prism on eleven dates, ending with December 2, when the comet was too far west for further observations.

As the identification of the knots in the spectrum could only be made by assuming the wave-length of some one of them, we attempted to get plates with a slit-spectrograph, attaching to the same telescope the small quartz spectrograph designed for use with the two-foot reflector. This instrument has collimator and camera lenses of "U.V." glass, of aperture 2 cm and focal length 15 cm, and a Cornu quartz prism of 60° angle. The scale of the plates is about one-sixth smaller than with the objective-prism.

Comparison spectra of helium and hydrogen were tried; the small tube of helium specially adapted for the apparatus unfortunately gave very strongly the spectrum of the negative pole of nitrogen,

largely masking the helium lines; the hydrogen tube could not be attached very conveniently. Metallic comparison spectra, for which the apparatus is arranged, cannot be well employed, as the lines run together too much with the wide slit necessary for the cometary spectrum.

We obtained our best results with the use of *Vega*, then not far from the comet, by allowing the star to trail along the portion of the length of the slit not occupied by the comet's head. The cross-wires in the guiding telescope made it possible to put the star at a desired position in the slit with considerable accuracy. The wave-lengths of the cometary bands were thus established with a better degree of precision than we had expected in view of the wide slit and small scale. Satisfactory plates were obtained with the quartz spectrograph on four nights, with exposures of from one to three hours, as indicated in the journal of observations. All of the plates were taken by Parkhurst with such assistance from Frost as was occasionally necessary.

On the evening of October 30 an exposure of 158 minutes was made by Frost and Barrett with the Bruce spectrograph (used with one prism) attached to the 40-inch refractor. Guiding was very difficult from the extreme faintness of the comet in the long-focus finder ($a=$ 10 cm, $f=19$ meters). No trace of an impression due to the comet could be detected on the plate. The great refractor, with its long focal length, is obviously unsuited for such an object.

In the column "Plate," S refers to the Seed "27;" Σ to the Lumière "Sigma" plate, of which recent emulsions show very high speed; and P-i denotes a Seed "27" bathed according to the Wallace "Pan-iso" formula.

In examining the first plate we were struck by the lack of a continuous spectrum, and a careful search for it has been made on all the plates. We can state that there is no certain evidence of its presence on any plate, whence we must infer that at this period the amount of reflected light was very small relatively to the intrinsic light from the radiations of carbon, cyanogen, and in the unidentified bands.

The general appearance of the spectrum is shown by Plates IV and V. The knots do not present the impression of bands, being images

PLATE IV

SLIT-SPECTOGRAPH

OBJECTIVE-PRISM

SPECTRUM OF COMET MOREHOUSE

1. Nov. 4, $6^h\ 0^m$ to $9^h\ 0^m$
   Comparison: *He* and *Ni*

2. Nov. 18, $5^h\ 30^m$ to $8^h\ 0^m$
   Comparison: *Vega*

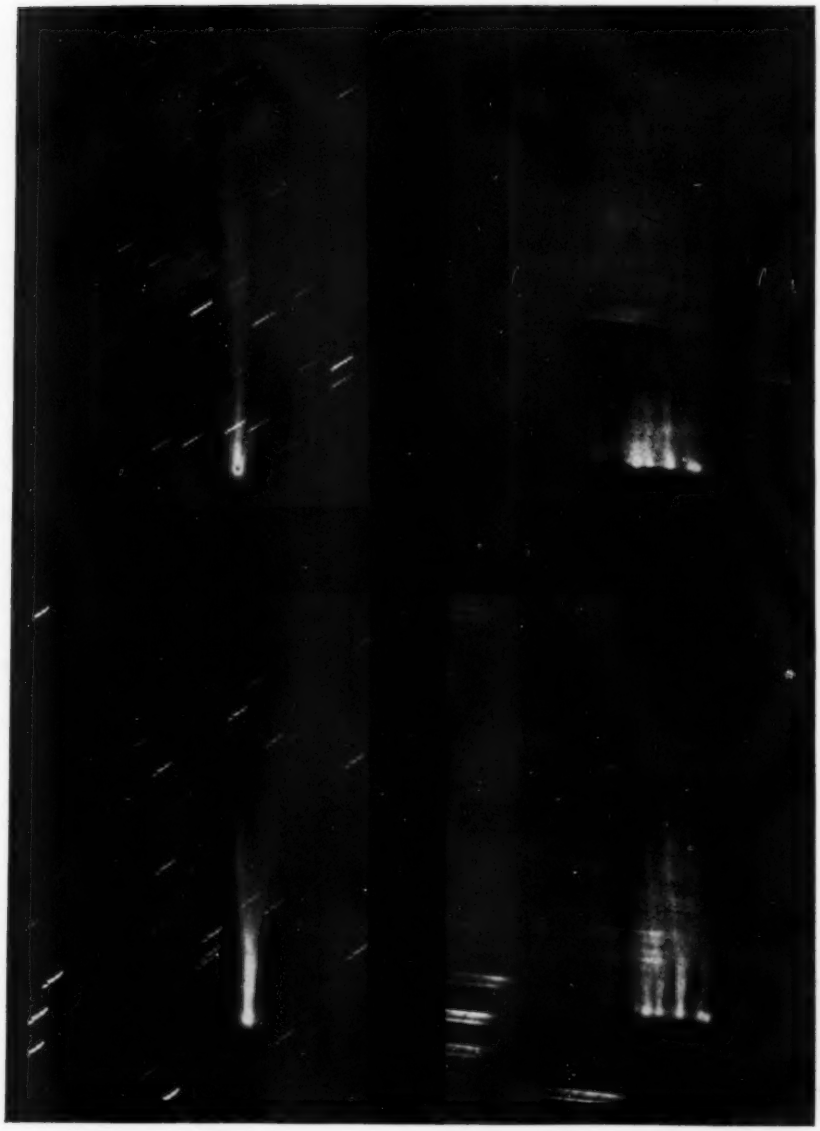
3. Oct. 30, $6^h\ 35^m$ to $7^h\ 11^m$
   "Pan-iso" plate

4. Nov. 19, $5^h\ 40^m$ to $6^h\ 40^m$
   Σ plate

PLATE V

3

4



1

2

BRUCE TELESCOPE, 6-INCH LENS OBJECTIVE-PRISM

DIRECT AND SPECTRAL IMAGES OF COMET MOREHOUSE

3. Oct. 30, $9^h\ 20^m$ to $10^h\ 30^m$ 4. Oct. 30, $8^h\ 56^m$ to $9^h\ 57^m$

1. Oct. 29, $8^h\ 56^m$ to $10^h\ 0^m$ 2. Oct. 29, $8^h\ 47^m$ to $9^h\ 21^m$

of the comet's entire head; with the quartz spectrograph and narrower slit, they become elongated, and also extend into the tail. Plate IV, Fig. 1, reproduces spectrogram Q 221, with comparison spectrum from helium tube, yielding chiefly the nitrogen bands. On the negative the tail appears above the comparison spectrum. In Fig. 2, from plate Q 226, the comparison spectrum was supplied by *Vega*. $H\beta$ is just visible at the right edge of the star's spectrum. The slit was here 0.07 mm wide, or about one-fourth as wide as in Fig. 1. The comet's bands here look like tadpoles, the extension upward being of course due to the comet's tail. Fig. 3 of Plate IV is given to show the knot in the green at λ 5165 as it appears on OP 220, taken on a plate bathed by the Wallace "Pan-iso" formula.

JOURNAL OF OBSERVATIONS

SLIT-SPECTROGRAPH PLATES

No.	Date	Begun C. S. T.	Ended C. S. T.	Plate	Slit-Width	Comparison Spectrum
	1908				mm	
Q 221....	Nov. 4	6^h 0^m	9^h 0^m	Σ	0.27	Helium tube
224....	16	5 39	7 49	Σ	0.07	*Vega* trails
225....	17	6 0	8 15	Σ	0.07	*Vega* trails
226....	18	5 30	8 0	Σ	0.07	*Vega* trails

OBJECTIVE-PRISM PLATES

No.	Date	Begun	Ended	Plate	Remarks
	1908				
OP 212...	Oct. 28	6^h 15^m	7^h 15^m	S	Good, streamers traced 1°
213...		7 25	8 25	Σ	Strong, streamers traced 2°
214...		8 52	9 17	S	Weak, thick sky
215...	29	6 22	6 40	S	Weak, thick sky
216...		7 5	7 40	Σ	Strong, fair
217...		8 47	9 21	Σ	Best plate
218...		9 25	9 58	P-i	Knot λ 5165 shown
219...	30	6 8	6 29	Σ	Strong, good
220...		6 35	7 11	P-i	Strong, good
221...		8 23	8 53	S	3 exposures, 5, 10, 15^m
222...		8 56	9 57	Σ	Very strong
223...	Nov. 5	6 7	6 22	Σ	Weak, moonlight
224...		6 24	6 34	Σ	Weak, moonlight
226...	9	7 23	7 35	Σ	Weak, moonlight
227...	11	6 22	6 57	Σ	Strong, good
229...	19	5 40	6 40	Σ	Strong, good
230...		6 42	7 6	Σ	2 exposures, 7, 16^m
232...	21	5 36	6 6	S	Very good plate
235...	28	5 27	5 49	S	Fair, short exposure, moon
238...	Dec. 1	5 30	5 50	S	Fair, short exposure, moon
239...	2	5 24	5 44	S	Fair, short exposure, moon

MEASUREMENTS

The plates were measured independently by the two observers with different machines; those taken with the slit-spectrograph were given the greater attention. The wave-lengths are referred to the hydrogen lines of *Vega*. Owing to photographic irradiation, dependent upon the intensity of the image, the edge of a knot is a very uncertain point to set upon, in no case a sharp edge. It was often impossible to set upon anything but the middle of a knot, but where feasible, settings were made on both edges.

The mode of reduction was also independent for the two observers. Frost employed a Hartmann formula derived from settings on $H\beta$, $H\gamma$, and $H\theta$, for the spectrograph plates, and similar formulae for the objective-prism plates from stellar spectra; for the ultra-violet region the formula was derived from $H\epsilon$, $H\eta$, and $H\mu$. The wave-length 4268, as obtained with the spectrograph for the center of the most symmetrical knot, was assumed for all objective-prism plates, of which Frost measured the best seven. The deviation of the separate values from the mean given in the table is less than might be expected; for instance, on the edge at λ 474, it is 7 tenth-meters; for the centers of the four best-defined knots (λ 4268 necessarily excluded), it is 3.5 tenth-meters.

Parkhurst derived his wave-lengths from a curve drawn from the stellar hydrogen lines. He measured ten of the best objective-prism plates in one direction, setting on the centers of the knots, and reduced by a curve from lines in the spectrum of *Vega*, then adjusting the wave-lengths to the system of the slit-spectrograph by using the wave-lengths of the five best-defined knots, λ 4716, 4601, 4268, 4015, and 3883. The agreement of these measures of the objective-prism plates may be regarded as satisfactory, the residuals from the mean of the ten plates averaging 5 tenth-meters, and the largest value, for a poor line, being 17 tenth-meters. The wave-lengths at the extreme ends of the spectrum are extrapolations and subject to some additional uncertainty, but they have been checked by measures on stellar plates extending to those regions.

In addition to the bands tabulated above, faint and doubtful lines were measured as follows on some of the objective-prism plates: by F. on four plates at λ 411, 415, 413, 414; by P. on three plates at

λ 413, 413, 413, mean λ 413. F. also measured a marking on three plates at λ 4369, 4390, 4376, mean λ 4378. We do not identify these.

In forming the "adopted wave-length," we have given to the determinations with the slit-spectrograph a weight of 3, the mean of the results of the two observers with the objective-prism receiving a weight of 1.

We avoid the still unsettled question of the precise origin of the "carbon" bands (of the so-called "Swan" spectrum) which have been so often ascribed to a hydrocarbon, specifically acetylene, and we use for them the simple designation "carbon."

The presence of the third and fourth bands on our plates seems to be beyond a doubt; the absence of the fifth band seems equally sure. The third cyanogen band is unquestionably present, and the fourth and first also appear to be assured; but the second is certainly lacking.

MEASURES OF PLATES WITH SLIT-SPECTROGRAPH

Measures on	Q 224		Q 225		Q 226		Mean
	F.	P.	F.	P.	F.	P.	
Edge	4744	4753	4734		4731	4743	4741
Middle		4720	4718	4721	4715	4709	4717
Edge	4679	4680			4697	4665	4680
Edge	4591	4602			4584	4592	4592
Middle		4571	4544		4568	4560	4561
Edge	4548	4542				4520	4537
Edge	4286	4291	4279	4290	4284	4293	4287
Middle	4267	4268	4265	4270	4262	4271	4267
Edge	4248	4248	4252	4250	4242	4240	4247
Edge	4020	4031	4020		4022	4041	4027
Middle	4014	4016	4012	4012	4013	4020	4014
Edge	4004	4002				3992	3999
Edge	3919	3924					3922
Middle		3915			3907	3921	3914
Edge		3905					3905
Edge	3894	3900			3886	3909	3897
Middle	3877	3884		3882	3875	3893	3882
Edge	3866	3869			3866	3872	3868
Edge	3801				3810		3806
Middle	3792	3790	3799		3796	3800	3795
Edge							

SUMMARY OF RESULTS

Band	Slit-Spectrograph Mean of F. and P.	Objective-Prism		Adopted Wave-Length	Probable Identification
		F.	P.		
Edge		5138			Third "Carbon" Band
Middle		5064	5086	5075	Edge at λ 5165.3
Edge		5013			(Kayser and Runge)
Edge	4741	4739		4741	Fourth "Carbon" Band
Middle	4717	4688	4699	4711	Edge at λ 4737.2
Edge	4680	4647		4672	(Kayser and Runge)
Edge	4592	4601		4594	First *CN* Band
Middle	4561	4556	4565	4561	Edge at λ 4606.3
Edge	4537	4518		4532	(Crew and Basquin)
Edge	4287	4310		4293	
Middle	4267	4267	4276	4268	?
Edge	4247	4224		4241	
Edge	4027	4049		4032	
Middle	4014	4024	4027	4017	?
Edge	3999	3998		3999	
Edge	3922	3931		3924	
Middle	3914			3914	?
Edge	3905			3905	
Edge	3897	3916		3902	Third *CN* Band
Middle	3882	3887	3887	3883	Edge at λ 3883.6
Edge	3868	3862		3867	(Kayser and Runge)
Edge	3806	3811		3807	
Middle	3795	3792	3790	3794	?
Edge		3776			
Edge		3703			
Middle		3687	3686	3686	?
Edge		3677			
Edge		3609	3594	3602	Fourth *CN* Band
Middle		3540	3528	3534	Edge at λ 3590.5
Edge		3510	3509	3510	(Kayser and Runge)

Attention may properly be drawn to the fact that the only lines in this region in the "line spectrum" of carbon are at λ 4267 and λ 3920, but this cannot be regarded as an identification. The edge of the first of these is at about 431, in agreement with a line photographed by Campbell[1] in comet 1893 II, falling at the edge of the violet carbon band at λ 4312 (Ångström and Thalén). The line at about λ 437 may be identical with a bright line photographed by Campbell in that comet at λ 4366.

[1] *Astronomy and Astrophysics*, **12**, 652, 1893.

We are aware that our results differ considerably from those published while our observations were in progress by MM. de la Baume Pluvinel and Baldet,[1] and by MM. Deslandres and Bernard,[2] who also employed prismatic cameras. The first-named observers agree with us in detecting no trace of continuous spectrum (dates reported, October 4, 5, and 7), and in seeing on the plate seven distinct monochromatic images of the comet. Their wave-lengths differ, however, materially from ours: for the first two knots being more than 100 tenth-meters less. For the knots of shorter wave-length the agreement is better. Their values are: λ 465–458; 448; 421; 397; 388–385; 376; 367. They regard the "carbon" bands as absent: "Ce qui frappe tout d'abord dans ce spectre, c'est l'absence des raies du spectre des hydrocarbures. La comète Morehouse semble donc faire exception a la règle générale, car on sait que les spectres cométaires présentent toujours les bandes des hydrocarbures." Per contra, they regard the cyanogen bands as fully represented: "Si le spectre des hydrocarbures fait défaut, le spectre du cyanogène se trouve au complet." We differ from them here in being unable to detect a trace of the second *CN* band, with its edge at λ 4216.

When they used a prism giving increased dispersion they found that all the images of the comet became double. We have examined our plates carefully for such duplication, particularly since these papers appeared in *Comptes Rendus*, but we cannot detect it, although on one or two plates there was a suggestion of duplicity at the band with center at λ 402.

MM. Deslandres and Bernard are unable to establish with certainty any trace of the "carbon" bands: "mais nous n'aurons pu constater aucune trace certaine des bandes des hydrocarbures, émises en général fortement par les comètes, surtout dans le vert." They also find a continuous spectrum on all of their plates (observations beginning on October 14): "il est visible dans la tête, et dans la queue jusqu'à une grande distance; mais il a une intensité relativement bien moindre que dans le comète Daniel."

The wave-lengths published by MM. Deslandres and Bernard are in excellent agreement with our determinations: our difference in interpretation or identification therefore represents a difference in

[1] *Comptes Rendus*, **147**, 666, October 19, 1908.

[2] *Ibid.*, **147**, 774, November 2, 1908.

judgment. As it is well established that measurements on cometary bands are likely to be systematically too small, we regard it as highly probable that a band measured at 4713 really has its edge at λ 4737, hence is the fourth carbon band.[1] Their values are as follows:

4713	4279	3881
4688	4256	3869
466	4232?	380
		3784
4572	4023	368
455	4003	356
4524	3914	333?

The bands with centers at λ 4561, 4267, and 4013 were also observed by them in comet Daniel, and similarly by Chrétien and by Evershed.

The relation between the knots and streamers shown on the objective-prism plates, and the corresponding direct photographs, is quite clearly shown in Plate V, where the spectrum plates of October 29 and 30 and the nearly simultaneous direct photographs taken by Professor Barnard with the Bruce camera are placed side by side. The focal lengths of the Bruce and Zeiss lenses are nearly the same, 78.4 cm and 81.4 cm respectively; and the engravings are on the same scale. The pictures would then be directly comparable were it not for the fact that the exposures with the Bruce were somewhat longer than with the Zeiss, and the light was concentrated in one image; so that the Bruce images are enlarged to a greater extent by photographic irradiation, which must be allowed for in making the comparison.

The relative intensities of the brighter head-knots cannot be inferred from the engravings, as the exposures were too long; but shorter exposures, for example on plates 221, 230, and 232, show that the knot at λ 3883 is the strongest photographically, followed in order by the knots at λ 4268, 4711, 4017, 4561, 3914, 3794, 3534, and 3686.

[1] A reference to Campbell's paper on the spectrum of Daniel's comet (*Astrophysical Journal*, **28**, 234, October 1908) shows that on plates taken with a slit-spectrograph with much higher dispersion, the same description "very bright, well defined" is applied to the first four edges of the fourth carbon band at λ 4737, 4715, 4697, and 4684. If these four bright radiations were run together by a low dispersion, the wave-length of the center would fall quite close to 4710. Is it impossible that some of the duplicities or complexities reported in the bands are due to the resolution of the additional edges?

This order also holds for the slit-spectrograph plates. On the Pan-iso plates the knot in the green at λ 5165 is about as bright as that at λ 4601. The photographs give no grounds for suspecting any change in the above order during the period of 33 days covered by the observations.

In tracing the relation of the tail-streamers to the knots, we are struck at first glance by the fact that the streamer proceeding from knot λ 4711, though certainly present, is very weak compared to the streamers from the fainter knots λ 4017 and 4561. A closer examination shows that the strongest knot of all, λ 3883, is also deficient in tail-material, the streamer which seems to accompany it in reality flowing mainly from the weaker knot λ 3914. Also these two knots deficient in tail-material extend farther on the side opposite the tail (i. e., toward the sun) than the other knots. The chemical origin given for the spectrum bands causing these knots does not explain the reason for these peculiarities.

The tracing of the separate streamers out into the tail is made difficult by their interlacing, but on the best negatives, OP Nos. 217, 222, and 229, they can be traced more than 2° from the head, *following the bends in the tail.* In Fig. 1, Plate V, the direct photograph shows two sharp streamers diverging 20° from the main tail on each side. These streamers can be seen on the corresponding objective-prism negative, diverging from the knot λ 4267, thus showing that particles of the same constitution are thrown out from the head at angles at least 40° asunder. The bearing of these facts on the theory of the constitution of the tail is evident.

With the two exceptions already noted, the relative intensities of the knots and their corresponding streamers are similar if not identical. Also the different plates which are similar in quality show practically identical spectra; so that, in spite of the extraordinary activity shown by this comet, the spectrum seems to have remained unchanged throughout the period covered by these observations.

It is obvious that comet Morehouse exhibited considerable differences in its spectrum from comet Daniel of the preceding year, one important effect of which was to make it photographically active. Such differences in comets are to be expected from past experience, and this emphasizes the importance of securing observations of faint comets

with objective-prisms at the earliest date when an impression can be secured. M. de la Baume Pluvinel seems to have been the first in recent years to call attention to the utility of this mode of observation, in his excellent paper[1] on comet 1902 *b*. His example does not seem to have been sufficiently followed, however, until Daniel's comet was investigated in this way by the observers already mentioned in this paper.

With a sufficiently long guiding telescope, it is possible before or after the exposure on the comet to place a neighboring star in a position where it may furnish with the prismatic camera a comparison spectrum, from which cometary wave-lengths may be inferred with some degree of accuracy without any assumptions. Of course the accuracy of the wave-lengths cannot compare with that yielded by a powerful slit-spectrograph. Besides having great light-power, the prismatic camera is alone capable of depicting the spectral images of the comet's tail and of showing the distribution therein of the constituent radiations. This is particularly important when internal changes are occurring rapidly, and masses of material are moving in the tail. This simple instrument is then wholly competent to test Bredichin's theory of a different chemical composition of differently curved tails. It may be remarked, incidentally, that the comparatively straight tail of comet Morehouse should have shown the spectrum of hydrogen, according to that theory, instead of that of "carbon" and cyanogen.

A further test of the theory will be readily given if plates were obtained anywhere with the prismatic camera on September 16 (or possibly on the days just preceding) when the tail was violently curved at a large angle from its direction before and after that date. The manner in which the "carbon" and cyanogen radiations follow the convolutions of the tail, as shown on Plates IV and V, make it seem a priori unlikely that an element not then showing its characteristic spectrum should do so when the deflection of the tail changes.

In the preparations for Halley's comet, it is therefore important that objective-prisms should be provided for the photographic doublets intended for its observation.

YERKES OBSERVATORY
December 1908

[1] *Comptes Rendus*, **136**, 743, 1903.

PLATE VII

South

COMET 1908 *c* (MOREHOUSE) ON NOVEMBER 15, 1908, AT $6^h\ 6^m$ C. S. T. EXPOSURE $0^h\ 40^m$
10-Inch Lens of Bruce Telescope. Scale: 1 cm = 0°.30

PHOTOGRAPHIC OBSERVATIONS OF COMET *c* 1908 (MOREHOUSE)

THIRD PAPER

By E. E. BARNARD

Since the two previous papers were written (see this *Journal* for November and December) the comet has presented a rather different series of phenomena, marked mainly by long, slender streamers at small angles to the tail and by convoluted forms in the tail itself. The previous pictures of it were not remarkable for individual long streamers or narrow rays. The new phenomena appeared about the middle of November. They gave the comet a very beautiful appearance, quite different from almost any of its previous aspects, and have added much to the interest of this remarkable body.

These new features are perhaps best shown on the pictures of November 14, 15, 16, 17, 18, and 19. Some of these rays are so straight and slender that they give the impression of being shot out with immense velocity. This is especially the case in the photograph of November 14, where a slender straight streamer apparently emanating in the north side of the tail, near the head, shoots out for about five degrees at an angle of 10° to the axis of the tail. The body of the comet is strongly undulating, like a ribbon waving in the wind, and has almost the shape of a corkscrew near the head.

The most remarkable of these photographs, however, though not the most beautiful, was obtained on November 15. In this picture the main tail widens out from a narrow neck attached to a rather small head, from each side of which broad diffused brushes of light issue at considerable angles to the tail. The ones on the north side extend for several degrees. On the south side of the comet two slender streams, apparently originating in the main tail, some distance back of the head, run back at a slight angle for several degrees. The outer one of these, at a distance of about 2°, rather suddenly makes a considerable bend southward as though something had deflected its course; it then seemingly runs back again. A similar appearance

is presented by the inner stream at a greater distance out. This last streamer is streaked along its middle with brighter strips. The main tail is brighter and full of structure, and at a distance of 5° from the head it bends northward at an angle of about 10° in a great curve that suggests a possible return to its original direction. Its north side is strongly undulating. At about two or three degrees from the head, in the middle of the tail, is a long, narrow, curved, bright strip, which is probably a streamer seen in projection; this has the same kind of deflection as the two south streamers.

In the photographs of November 17 the tail is full of irregular bright masses and there is a general convexity on the south side, in the direction of motion. A very slender curved line runs parallel to the north side and seems to begin at the edge of the tail 2° from the head. It can be traced to a distance of about 8°. On each side of the head a slender streamer is visible for about 2°. The tail connects with the head by a very slender sinuous neck. There are decided changes in the comet in the interval of 1¼ hours between the two photographs on this date.

The original photograph of November 19 is an exquisite picture. The tail seems to be made up of sheetlike streams which are very sharp at their edges; the neck, near the head, has a twisted aspect. Of a similar nature and equally beautiful is the photograph of November 16. That of November 18 is also very beautiful. On this last date great numbers of delicate streamers shoot out symmetrically from the head for several degrees. The main body of the tail is streaked and undulating and several degrees back it brightens up in curved masses. The entire comet is rich with sharp details and is a very striking object. Indeed, one of the most remarkable things about the later pictures of this comet has been the extreme sharpness of the structural details near the head. In this respect they are quite different from our general ideas of a comet.

In any attempt to explain certain of these features of the comet we are forced to tread on very dangerous ground, for there is nothing in the adopted theories of comets that will explain them, and we must assume unknown quantities that perhaps violate all our ideas of the conditions existing in space in the vicinity of the sun and planets. But, as there seems to be no other explanation, the very fact that we

PLATE VIII

South

COMET 1908 *c* (MOREHOUSE) ON NOVEMBER 16, 1908, AT 7^h 10^m C. S. T. EXPOSURE 1^h 3^m
10-Inch Lens of Bruce Telescope. Scale: 1 cm = 0°.30

PLATE IX

South

COMET 1908 *c* (MOREHOUSE) ON NOVEMBER 18, 1908, AT $7^h\ 25^m$ C. S. T. EXPOSURE $1^h\ 10^m$
10-Inch Lens of Bruce Telescope. Scale: 1 cm = 0°.30

are driven to extremes in the search for a possible cause may lead to a knowledge of interplanetary conditions that would never become known without the aid of the wide sweeping tail of a comet.

What caused the deflection in the streamers of November 15? Certainly not the sun or the comet. As I have suggested long ago, in connection with another comet, there must be some influence at work independent of the pressure of the sun's light and of the forces at work in the head of the comet to make these sudden changes in the direction of a comet's tail or of its streamers. If we should suppose that there are electrical conditions existing in the tail of the comet—which is highly probable—a possible repulsive condition might exist locally at points in the tail which would force the flow of the particles outward; or if the conditions were right they might be attracted toward the seat of disturbance. This is a subject, however, for the electrician and physicist.

Are there currents in interplanetary space across which the tail may sweep? This is strongly suggested in previous cases—especially in the case of Brooks's comet of 1893 on November 2, where the end of the tail is bent suddenly backward almost at a right angle, and where the main tail is strongly concave in the direction of motion. (See *Astrophysical Journal*, **22**, 251, 1905.) The appearance on that date strongly suggests that the tail was beating against a resistance of some sort in its onward flight. A similar case occurred in Morehouse's comet on September 16 where the tail is violently curved from its original direction. In this case, however, the direction of deflection is in the direction of motion—ahead of the radius vector; or in other words, the tail as it left the comet *rapidly moved forward faster than the comet itself*. There must have been some force that carried the tail forward. The resultant of the outward flow of the particles and the onward motion of the comet might have curved the tail but it could only make it move more slowly than the comet and hence deflect it in the opposite direction to that shown in the photograph of September 16. I have already called attention, in *Popular Astronomy* for December 1908 (**16**, 593), to the fact that the masses in the tail of the present comet on October 15 were moving faster through space (perpendicular to the radius vector) than the comet itself.

In pursuance of this subject I may be permitted to quote the follow-

ing from a paper of mine in *Monthly Notices* of the Royal Astronomical Society, **59**, 355, March 1899:

> Unlike the planets, the comets often traverse the entire solar system. They are, therefore, our only means of exploring the regions between the planetary orbits. Instead of ponderous bodies like the planets, they are but flimsy creations of enormous dimensions. They are thus likely to be easily subject to disturbances in their forms that would produce no perceptible effect on their motions. What these influences may be we do not know: probably swarms or streams of meteors, which we know do exist in space, or possibly some other cosmical matter yet unknown. Such objects might be (and possibly have been) revealed to us by their effect upon the form of the comet's tail as it sweeps through space.

I believe these remarks are just as pertinent today as they were ten years ago.

After November 21 continued cloudy weather prevented any observations of the comet until November 28 when an exposure was secured in a moonlit and densely hazy sky. Clouds again cut off the view until December 1 and 2 when a bright moon interfered badly, and after this cloudy weather occurred again.

LIST OF NEGATIVES OF THE COMET

(Continued from the December number)

Central Standard Time	Middle of Exposure	Duration	Central Standard Time	Middle of Exposure	Duration
1908			1908		
Nov. 13.....	6h 25m	0h 59m	Nov. 20.....	6h 35m	1h 50m
13.....	7 58	1 5	20.....	7 55	0 40
14.....	6 47	1 2	21.....	6 9	1 11
15.....	6 6	0 40	28.....	6 8	1 18
16.....	6 7	0 48	Dec. 1.....	5 55	0 41
16.....	7 10	1 3	2.....	5 43	0 22
16.....	8 19	0 44	2.....	6 15	0 24
17.....	6 21	1 13	4.....	6 14	0 26
17.....	7 37	1 0	7.....	5 43	0 20
18.....	6 7	1 1	9.....	5 56	0 36
18.....	7 25	1 10	11.....	5 59	0 38
19.....	6 9	1 3	13.....	5 55	0 33
19.....	7 25	1 9			

With the exception of November 16, 17, and 20 and December 2 the exposures with the 3.4-inch lens were simultaneous with the other two lenses. The following table gives the exposures with this lens for the above dates:

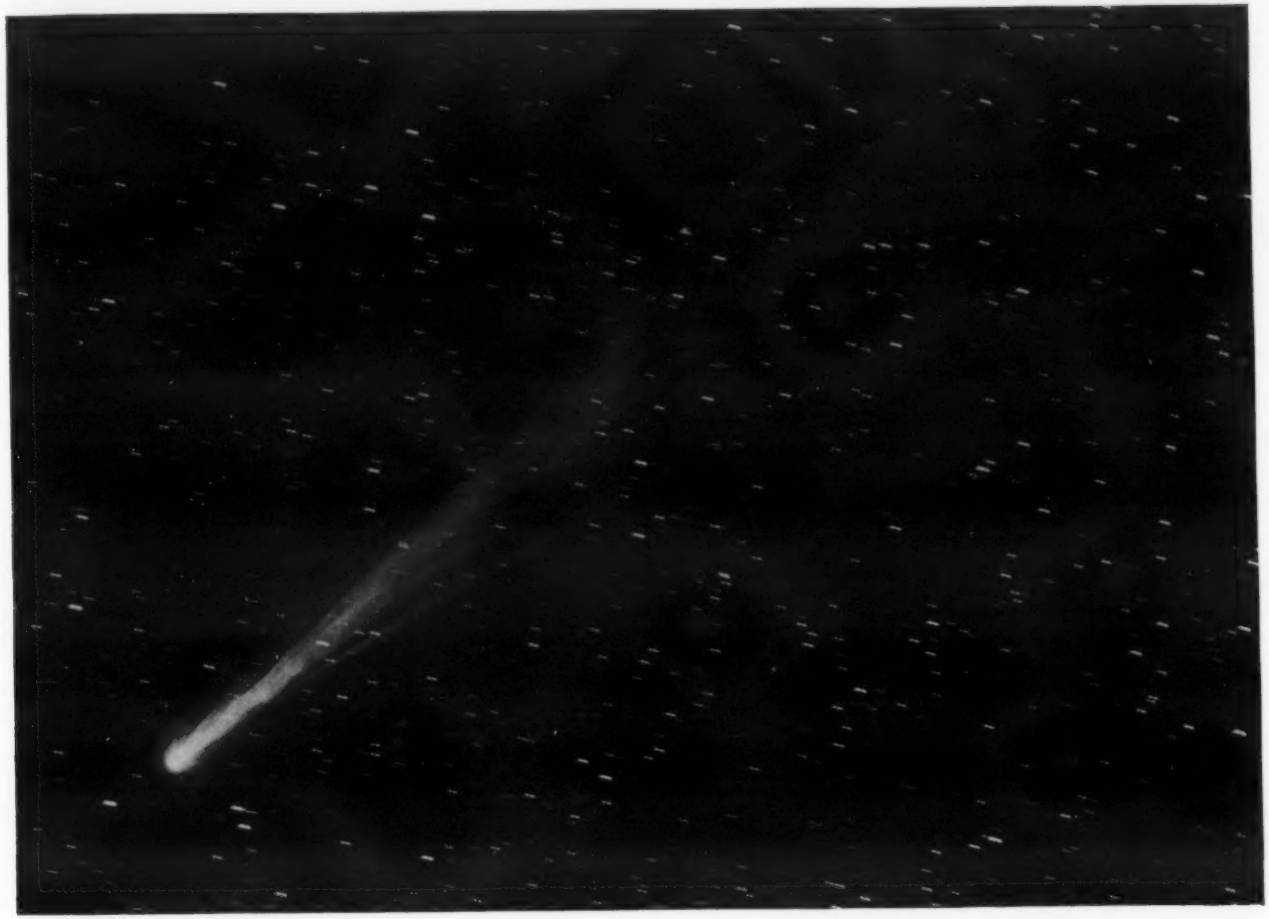
PLATE X

South

COMET 1908 *c* (MOREHOUSE) ON NOVEMBER 19, 1908, AT $6^h\ 9^m$ C. S. T. EXPOSURE $1^h\ 3^m$
10-Inch Lens of Bruce Telescope. Scale: 1 cm = 0°.30

PLATE VI

South



COMET 1908 *c* (MOREHOUSE) ON NOVEMBER 14, 1908, AT $6^h\ 47^m$ C. S. T. EXPOSURE $1^h\ 2^m$
10-Inch Lens of Bruce Telescope. Scale: 1 cm = 0°.30

Central Standard Time	Middle of Exposure	Duration	Central Standard Time	Middle of Exposure	Duration
1908			1908		
Nov. 16	$6^h\ 14^m$	$1^h\ 5^m$	Nov. 20	$6^h\ 57^m$	$2^h\ 35^m$
16	7 46	1 50	Dec. 2	6 0	0 55
17	6 56	2 22			

In the following table is given the approximate length of the comet's tail taken from the photographs made with the small lens. Clouds, moonlight, or bad sky, in some cases, will have prevented all the tail being shown, but in general I think the full length is visible on these plates. On November 15, by averted vision, I could faintly trace the tail with the eye for 10°, as measured on a star chart. The exposure on this night was cut short by clouds which would doubtless account for the less length of the tail on the photographs. Yet on the picture with the 6-inch lens it can be traced readily for 10°—to the edge of the plate.

ESTIMATES OF THE LENGTH OF THE TAIL OF THE COMET FROM NEGATIVES WITH THE 3.4-INCH LENS

1908		1908		1908	
Sept. 2	3°	Oct. 9	4°	Nov. 9	7°
6	4	11	9	10	9
7	2	12	7	11	10
8	4	13	6	13	7
16	4	14	7	14	8
18	2	15	8	15	8
19	3	16	5	16	10
21	6	17	6	17	9
23	6	21	7	18	10
25	6	28	9	19	10
26	6	29	9	20	8
29	6	30	11	21	8
30	9	31	9	28	8
Oct. 1	8	Nov. 1	8	Dec. 1	7
2	6	2	7	2	4
3	8	3	8	4	3
4	4	4	9	7	2
5	7	5	9	9	7
6	8	6	6	11	8
7	4	8	7	13	3
8	3				

In reference to the great disturbance of September 30, remnants of the tail discarded by the comet on that date are also visible on the

plates with the small lens on October 2 and 3 (besides, of course, on October 1, where the old tail is conspicuous).

The beginning of the disturbance shown in the tail on October 6, which so much resembles that of October 15, is doubtless visible on the plates of October 5, where there is a large mass—really the rear end of a disconnected tail—at a distance of about $\frac{1}{2}^\circ$ from the head. Evidences of this disturbance are still seen on the photographs of October 7.

YERKES OBSERVATORY
December 5, 1908

ADDENDUM

Since the above was in type there have appeared in *Astronomische Nachrichten*, No. 4287, a photograph of the comet taken on October 15 at the Observatory of Geneva by M. Pidoux, and in *Bulletin de la Société Astronomique de France* for December a photograph taken on the same date by M. Quénisset at Juvisy (M. Flammarion's observatory). These pictures add a remarkable interest to the comet, for they clear up any uncertainty as to the origin of the masses shown in the tail of the comet on that date (see Plate XXXII in the *Astrophysical Journal* for December 1908). The first of these photographs was made about 8 hours and the other 7 hours earlier than my photograph. On the Geneva picture at about 20′ from the head there is a strong bend in the tail but no masses. On the Juvisy plate this bend is stronger and more suggestive of the appearance shown on the photographs taken in this country. It is very clear from these pictures that the masses were not thrown off as such from the comet, but had their origin in a disruption of the tail which must have occurred a short time previous to Greenwich $7^h\ 0^m$ on October 15. This accords exactly with my idea that the tail of the comet suffered encounters with some sort of disturbing medium in space. If there should be photographs made several hours previous to the picture by M. Pidoux, it will doubtless be seen that the tail was straight and that it subsequently encountered something that bent and distorted it. What that something is I have tried to show in a paper read before the meeting of the Astronomical Section of the American Association

for the Advancement of Science, at the Baltimore meeting in December, present. In that paper I have shown that there must be some influence, perhaps of a local and temporary nature, in the planetary spaces that can retard or accelerate, and disrupt a comet's tail when struck by it. It was suggested that this may come from energies originating in disturbances on the sun—perhaps of a similar nature to those that cause magnetic disturbances and auroral effects on the earth.

The comet has now passed to the southern hemisphere and is out of reach of all northern observatories. Cloudy weather here in the first half of December permitted but few observations of the comet. Exposures were made, however, every time that it could be seen. The last picture was made on December 13, when the comet was close to the horizon. This showed a tail about 3° long. The plates of December 9 and 11 are very interesting. The one of the 11th is very remarkable—indeed it is one of the most remarkable of the entire series. Though the comet was close to the horizon on that date, the tail shows for a length of 8°. It is convex on the south side—in the direction of motion—and looks as if it were encountering a resistance. About 2° from the head is a mass 30′ long; while at a distance of 2° 50′ a considerable portion of the tail is apparently shattered and thrown away to the north. On December 9 a peculiar mass appears in the middle of the tail, while the outlines of the tail are definitely bounded by two diverging streamers.

By additions to the proofsheets I have made the above list complete for my series of photographs of the comet. It is to be hoped that other observers will print similar lists so that the photographic history of the comet may be known and located.

ERRATUM.—In my paper in the December number, in the fifth line from the foot of p. 387, for October 27 read October 29.

December 31, 1908

ON THE COLORS OF SOME OF THE STARS IN THE GLOBULAR CLUSTER M 13 *HERCULIS*

By E. E. BARNARD

Over eight years ago in the *Astrophysical Journal* for October 1900 (**12**, 176–181) I called attention to some "abnormal" stars in the globular cluster M 13 *Herculis*. It was shown that certain stars of the cluster which were visually faint were relatively very bright on a photograph taken with the Potsdam Astrographic refractor. So great was this difference that I thought the stars in question were variable, but they did not prove to be so. The most remarkable of these is Scheiner 148 which, though faint visually, is the brightest star on the Potsdam photograph. It is evident that these photographically bright stars are bluer and hence their light is more actinic than the average stars of the cluster.

Since the publication of the above paper I have found other stars of this class in M 13 and also in M 5 *Librae*. About six months ago it occurred to me to compare a photograph of M 13, made with the Potsdam refractor, with one made with the 40-inch telescope and a yellow color-screen. The two pictures were copied to the same scale (in the negative form). They were then placed in the "Blink Microscope" of the Zeiss stereo-comparator. With a single eyepiece and two sets of prisms this instrument permits two negatives of the same object to be seen at once superposed. By the aid of a small movable blind, one picture is alternately made instantly to take the place of the other. If any object is on one photograph and not on the other (or if there in an altered condition), it will at once attract the eye in a most striking manner.

When these two plates were thus examined with the blink microscope, the result was very remarkable. It was seen at once that there were more of these "blue" stars in the cluster than I had found visually. It was also shown that there was a considerable number of yellow stars. These last were faint on the Potsdam plate but relatively bright on that with the 40-inch. Of course, visually, it is not possible

to detect any color in stars as faint as those forming M 13. They all look alike except in relative brightness. From such an inspection one would think that the stars in the cluster were all white. The above experiment shows, however, that in reality M 13 consists of stars of different colors and hence of different spectral types.

I am making a catalogue of these blue and yellow stars in M 13 and hope to do the same for some of the other globular clusters. It will be interesting and important to study the distribution of these differently colored stars in such clusters. There seems to be a tendency to grouping of these objects in some parts of the cluster.

I give here a brief list of some of the blue stars (those abnormally bright on the Potsdam plate), and also a list of some of the yellow stars (those abnormally bright on the 40-inch plate with yellow color-screen). The numbers are those assigned by Dr. Scheiner in his photographic catalogue of the stars in M 13 ("Der Grosse Sternhaufen im *Hercules*, Messier 13"). The numbers in parentheses are provisional numbers given by me. The places of these last stars are only approximate. Where the Scheiner number is questioned the identification is not certain. The positions refer to Scheiner's zero star No. 382, which is in the north edge of the brightest part of the cluster. A negative sign indicates preceding in α and south in δ.

BLUE STARS

	$\Delta\alpha$	$\Delta\delta$
148	−1′ 22″	−1′ 44″
171 (8)	−1 14	−1 20
175	−1 12	−1 15
179	−1 11	+0 1
188	−1 6	+1 23
216	−0 54	−0 3
234	−0 45	+3 0
382	0 0	0 0
393	+0 4	−0 26
547	+0 45	+1 14
592	+1 1	+0 46
(23)	+1 3	−0 38
630	+1 13	−0 25
667	+1 33	+1 16
749	+2 21	−1 25
766	+2 43	−1 24

The star 148 is *very* blue

YELLOW STARS

	$\Delta\alpha$	$\Delta\delta$
16	−4′ 35″	−1′ 36″
19	−4 27	−1 8
38	−3 46	+0 7
41	−3 37	+0 17
(42)	−3 32	−2 16
44	−3 26	+0 20
(12)	−3 25	−2 1
57	−2 51	+0 47
(35)	−2 47	+0 47
61	−2 45	−2 21
(28)	−2 41	−0 58
64	−2 39	+0 54
66	−2 36	+1 2
(45)	−2 20	−0 11
108	−1 55	−1 36
120	−1 48	−1 35
138	−1 32	−1 41
152?	−1 22	−0 58
171 (9)	−1 14	−1 20
203	−1 0	−0 49
(18)	+0 36	+1 45
582	+0 58	−2 15
607	+1 5	+2 40
611?	+1 6	+3 54
637	+1 16	+2 12
661	+1 30	−4 18
677	+1 35	−4 20
686	+1 39	−3 25
(43)	+1 52	−0 48
769	+2 48	−0 40

A striking example of this difference of color is shown in (8) and (9) which occupy the place of Scheiner 171 and which with Scheiner 166 form a small close equilateral triangle. On the 40-inch plate these three stars are equal in brightness. The blink microscope, however, shows that (8), which is the following of the two, and (9) are strongly contrasted in color, (9) being strongly yellow and (8) blue while the third star, 166, is normal.

The two known variables in this cluster which were discovered by Professor Bailey, and which I have identified as Scheiner 216 and 630, are both blue stars. At their maxima, at which time comparisons are more readily made, they are relatively brighter with the regular photographic refractors and reflectors than they are visually. The variability of the first one of these (216) was independently discovered visually by me (see *Astrophysical Journal*, **12**, 182–184, 1900,

where it was supposed to be new). I have determined the period of 216 to be 5.1 days, and that of 630 to be 6.0 days.

There seem to be several other variables in the cluster. I have not verified their variability yet with certainty, but they are under observation.

I should state that in comparing with other photographs, made with the 13-inch Boyden photographic refractor of the Harvard College Observatory and with the 33-inch correcting lens over the 36-inch object-glass of the Lick refractor, the differences to which I have called attention are not nearly so marked, though they are evident. It would seem, therefore, that the Potsdam telescope is corrected to give a stronger violet image than the other two refractors.

YERKES OBSERVATORY
November 11, 1908

ON THE SEPARATION IN THE MAGNETIC FIELD OF SOME LINES OCCURRING AS DOUBLETS AND TRIPLETS IN SUN-SPOT SPECTRA[1]

By ARTHUR S. KING

In the "Addendum" to Professor Hale's paper "On the Probable Existence of a Magnetic Field in Sun-Spots,"[2] it was stated that a number of the iron and titanium lines appearing as doublets in the spectra of sun-spots appeared as doublets also in the spectrum of the spark in the magnetic field when observed at right angles to the lines of force, the sun-spot triplets also retaining their character when observed in this manner. This of course referred to the appearance of the lines under the dispersion then used, leaving open the question whether they would show a higher order of separation when studied with a view to determining this. The next step was to observe the polarization of the components, and this has brought out the fact that all of the doublets listed in the "Addendum" are in reality quadruplets, and the list has been much extended, especially on the side of the titanium spectrum, which has been photographed through the range from λ 4400 to λ 6400, not only with the light parallel to the lines of force and also at right angles to them, but in addition a set of photographs has been obtained in which the light at right angles to the lines of force was passed through a Nicol prism in two positions 90° apart. This operation separated the light vibrating parallel to the force lines, producing the middle component of the normal triplet, from the light whose vibrations are in a plane perpendicular to the lines of force, giving the side components of the normal triplet. The great majority of the iron and titanium lines show the regular behavior of the normal triplet, the middle component remaining single; but for the lines appearing as doublets in sun-spots, the Nicol when turned so as to transmit

[1] *Contributions from the Mount Wilson Solar Observatory*, No. 34.

[2] *Contributions from the Mount Wilson Solar Observatory*, No. 30; *Astrophysical Journal*, **28**, 315–343, 1908.

the light with vibrations parallel to the lines of magnetic force gives the middle component, in all but two cases, either as a doubled line or one of such widened and diffuse appearance that evidently only a lack of sufficiently high dispersion stands in the way of a clear resolution of the components. The spot triplets retain in all cases their sharp middle component when examined in the laboratory at right angles to the lines of force.

The following table gives the character of each line in the spark with the measurements of its components. The last column, giving the appearance of the line in sun-spots and measurements when these could be made, was kindly contributed by Mr. Adams. Most of the measurements of spark lines were made by Miss Wickham. The magnetic field usually employed with the titanium spark was 12,500 gausses; for iron about 15,000 gausses. When a stronger field was employed for the separation of difficult lines, as in the blue of titanium, the measurements were reduced to the standard field. As the separation of the lines given at right angles to the field by the light vibrating in a plane perpendicular to the lines of force is the same as that given by the light observed parallel to the lines of force, photographs taken in the latter way were sometimes used when better measurements could be thus obtained; though for most of the titanium spectrum good photographs were available for the two positions of the Nicol.

IRON

λ	Spark Observed at Right Angles to Force Lines	$\Delta\lambda$ Spark, Transverse Effect*	$\Delta\lambda$ Spark, Longitudinal Effect*	Character in Sun-Spots
6173.55	Triple	Not separated	1.094	Wide triplet. Central line about $\frac{3}{5}$ intensity of side components
6213.14	Quadruple	0.460	0.840	Wide doublet. $\Delta\lambda = 0.136$
6256.57	Quadruple	0.438	Narrow. Components diffuse	Widened 3.† No evidence of doubling
6301.72	Quadruple	0.287 (scarcely resolved)	0.792	Wide doublet. $\Delta\lambda = 0.138$
6302.71	Triple	Not separated	1.144	Wide triplet. Central line about $\frac{3}{5}$ intensity of side components
6337.05	Quadruple	0.431	0.880	Wide doublet. $\Delta\lambda = 0.172$

* These columns refer to the spark in the magnetic field when observed across the lines of force and along them respectively.

† The estimates of widening are on an arbitrary scale of 0 to 5.

TITANIUM

λ	Spark Observed at Right Angles to Force Lines	Δλ Spark, Transverse Effect*	Δλ Spark, Longitudinal Effect*	Character in Sun-Spots
4440.49	Quadruple	0.144	0.182	Narrow. Strengthened but scarcely widened
4444.73	Quadruple	0.189	0.202	Narrower than in disk and probably slightly weakened
4450.65	Sextuple	0.189	0.245 (mean for two pairs)	Possibly slightly strengthened; not widened. Enhanced line
4464.62	Quintuple	0.213	0.204 0 0.214	Slightly weakened and narrowed
4471.02	Quadruple	0.398	0.460	Widened 2
4471.40	Septuple	Too diffuse to measure	Inner pair 0.094 Outer pair 0.258	Widened 2. Much strengthened
4439.24	Quadruple	0.134	0.329	Widened 2. Blends with 4489.3
4527.48	Septuple	0.124 0 0.122	Inner pair 0.232 Outer pair 0.510	Widened 3. No evidence of doubling
4529.65	Quadruple	0.181	0.258	Blends with 4529.7. Apparently little affected
4544.83	Septuple	0.124 0 0.127	0.497 (mean for two pairs)	Blends with 4544.7. Much strengthened. Widened 1–2
4590.11	Quadruple	0.207	0.257	Widened 1? Slightly weakened. Enhanced line
617.45	Quadruple	Not clearly resolved	0.311	Widened 2. Much strengthened
4623.24	Quadruple	0.091	0.288	Widened 2. Much strengthened
4629.52	Quintuple	0.136 0 0.132	Too weak to measure	Widened 1. Slightly strengthened
4639.54	Quadruple	0.163	0.457	Widened 3. No evidence of doubling
4639.85	Quadruple	0.138	Too weak to measure	Widened 3. No evidence of doubling
4640.12	Quadruple	0.254	0.592	Widened 4. No evidence of doubling. Fringed to the red
4645.37	Triple	Not separated	0.244	Widened 4. Probably double
4698.94	Quadruple	0.081	0.293	Widened 2. Much strengthened
4710.34	Quadruple	Not clearly resolved	0.375	Much strengthened but narrow. Widened 1?
5016.32	Quadruple	0.204	0.426	Widened 2. No evidence of doubling
5020.17	Quadruple	0.218	0.384	Widened 3. No evidence of doubling
5023.02	Quadruple	0.241	0.374	Widened 3. No evidence of doubling

* These columns refer to the spark in the magnetic field when observed across the lines of force and along them respectively.

TITANIUM—*Continued*

λ	Spark Observed at Right Angles to Force Lines	Δλ Spark, Transverse Effect*	Δλ Spark, Longitudinal Effect*	Character in Sun-Spots
5025.03	Quadruple	0.412	0.108	Widened 3–4. No evidence of doubling
5066.17	Quadruple	0.283	0.227	Blends with 5056.08 *Cr.* Difficult. Apparently widened 2
5085.51	Quadruple	0.319	Not measurable	Widened 3
5109.60	Quadruple	0.259 (difficult)	Not measurable	Widened 2
5418.98	Quadruple	0.292	0.395	Large shift to red in spot. Widened 2. Maximum toward red side of line. Enhanced line
5426.47	Quadruple	0.408	0.532	Widened 3. Probably double. Measured separation 0.085
5460.72	Quadruple	0.431	0.568	Widened 4. Maximum at about center of line
5481.65	Quadruple	0.429	0.429	Narrow. Fringe to violet making hazy, continuous band as far as λ 5481.45
5712.07	Quadruple	0.313	0.550	Widened 4 but blends with 5712.10 *Fe.* Difficult to judge structure. Possibly double
5716.67	Quadruple	0.417	0.256	Widened 4. Possibly double though line appears of nearly uniform intensity throughout. Apparent components measured 0.105
5720.57	Quintuple	0.630	0.338 0 0.340	Widened 4. Narrow, sharp maximum in center of line
5903.54	Triple	Not separated	0.601	Widened 4. Probably double. Apparent components measured 0.094
5938.04	Quadruple	Wide and hazy, not clearly resolved	0.612	Widened 4. Double. Δλ = 0.093
5941.98	Quadruple	0.456	0.527	Widened 4. Double. Diffuse center. Δλ = 0.113
6064.85	Triple	Not separated	0.876	Widened 5. Triple. Δλ = 0.087, 0, 0.092
6085.47	Quadruple	0.225	0.808	Widened 4. Not clearly doubled
6303.98	Quadruple	0.487	0.493	Widened 3. Double. Δλ = 0.087
6312.46	Quadruple	0.367	0.615	Widened 3. Double. Δλ = 0.090

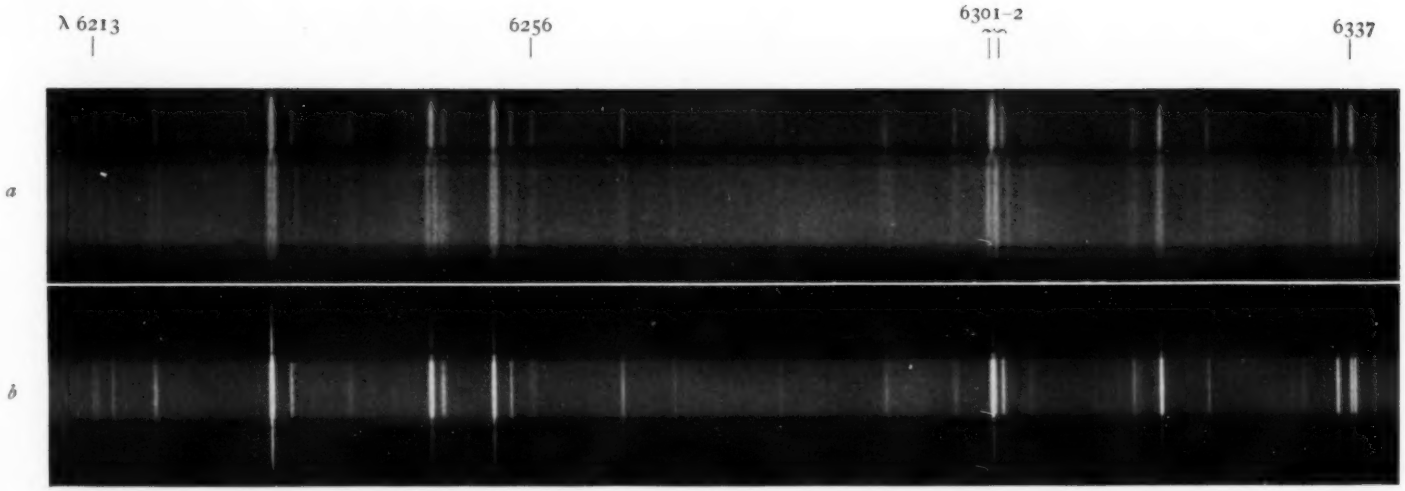
* These columns refer to the spark in the magnetic field when observed across the lines of force and along them respectively.

Plate XI reproduces the iron spectrum from λ 6213 to λ 6337 given by the spark in the magnetic field. The upper spectrum shows the doublets obtained when the spark is observed parallel to the lines of force, the so-called "longitudinal component." The lower was made with the light at right angles to the force lines and passing through a Nicol prism turned so as to transmit the light vibrating parallel to the field, the "transverse component." The quadruplets thus appear as narrow doublets in the latter spectrum, while the triplets show their middle component single.

The purpose of the table is to show to what extent a correspondence exists between the structure of lines given by the spark in the magnetic field and by the sun-spots. This may be discussed best by considering each type of separation in turn.

1. The fairly large group of *quadruplets* in the spark is of special interest when compared with the list of spot doublets. For iron there is practically a complete correspondence for the limited region in the red thus far examined with the Nicol prism. The only apparent exception is λ 6256.57. This is much widened in the spot but does not appear doubled. In the spark it is an unusual type of quadruplet. The transverse component is clearly separated (see Plate XI) while the parts of the longitudinal component are wide and hazy and not clearly resolved. A line of this character, in the weak field of a sun-spot, would have the central portion so filled up that no separation of the parts could be effected. For titanium the correspondence is very close for lines in the yellow, orange and red, beginning at about λ 5700. The most important exception is λ 5903.54, which is much widened in spots and probably double. This line shows in the spark the structure of the normal triplet, the transverse component being narrow. Two extreme types of quadruplets are represented in λ 5941.98 and λ 6085.47. The former has in the spark the character of the iron line λ 6256.57 mentioned above, the transverse component having a wide separation while the longitudinal is separated but little more and the central portion is so filled up by the diffuse and hazy components that a measurement is difficult. The spot line is of an analogous type, having the center filled up, but the maxima at the sides are sufficiently distinct to enable it to be classed as a doublet. λ 6085.47 has its transverse component very

PLATE XI



SPECTRUM OF IRON SPARK IN MAGNETIC FIELD

(*a*) Observed along Lines of Force (Longitudinal Effect); (*b*) Observed across Lines of Force, with Outer Components Removed by Nicol (Transverse Effect)

narrowly separated, with a widely separated longitudinal component. In the spot this line is widened, but not doubled.

In the region of shorter wave-length, the agreement is not nearly so good. λ 5645.37 shows the same relation in spark and spot as λ 5903.54. Several weak and doubtful spot doublets in the blue and green are probably narrow quadruplets in the spark, but are not included in the table. The lines in this region which are clear quadruplets in the spark, however, have no uniform behavior in the spot. Many are considerably widened (1 to 3 on a scale of 5), but do not show doubling, while a few are slightly narrowed in the spot. The change in correspondence begins to show itself in the neighborhood of λ 5000, and the lack of agreement with the region of greater wave-length points to a masking of the real character of the spot lines, presumably by the same agency which causes other influences, such as temperature, to show a much closer accordance between laboratory and spot results in the less refrangible region of the spectrum.

2. The few lines of iron and titanium occurring as *triplets* in sun-spots show a complete agreement with the laboratory results. $\lambda\lambda$ 6173.55 and 6302.71 of iron and λ 6064.85 of titanium are all wide triplets in the spark, the middle component remaining sharp. The latest measurements of the best photographs show that λ 6302.71 is not asymmetrical, and indicate that the appearance of asymmetry previously noted was due to disturbing influences in both spot and spark spectra.

3. The few titanium lines appearing as *quintuplets* and of still higher separation in the region studied are of two types. $\lambda\lambda$ 4464.62 and 5720.57 appear as triplets when observed along the lines of force in the laboratory and as quintuplets across the lines of force, two more components being added on the outside when viewed at right angles. Such a line will then have a strong central component at whatever angle to the force lines the light may be taken. λ 5720.57 is favorably located for comparison with the sun-spot line. In the spot the line is very much widened and has a narrow and unusually strong maximum in the center. The structure of the spark line should give this appearance, the quintuplet structure giving a strong widening, while the central maximum is accounted for. In λ 4464.62 the strength of the central component is probably partly responsible

for the apparent narrowing of a rather faint line, the sides being weak and indistinct by contrast with the center.

The other type has one or more pairs of rather widely separated components when viewed along the lines of force; while across the lines of force a close triplet is seen in the middle of the structure. Lines of this type are $\lambda\lambda$ 4471.40, 4527.48, 4544.83, and 4629.52, and by referring to the table these are seen to be both widened and strengthened in sun-spots, in no case doubled. This again accords well with the spark structure, the widely separated components giving a broad line, while the central maximum is not so conspicuous as in the first type.

4. One strong *unseparated* line stands out with great distinctness in the titanium spectrum. This is λ 5714.12, which appears equally narrow in both positions of the Nicol. This line is remarkable for its narrowness in the spot spectrum.

We have thus a good deal of evidence that light coming at an angle to the lines of magnetic force plays a large part in giving the sun-spot lines the structure which is observed. The presence of triplets in the spot spectrum is fully explained. The fact that the spot doublets occur very generally as quadruplets in the laboratory when observed at right angles to the lines of force obviates the necessity of assuming that doublets in the spot are due to the action of the field along the lines of force alone, since in either case the central component would be absent for these lines.

The two inner components of the quadruplets are seldom widely separated, even in the fairly strong laboratory fields; so that what we probably have in the spot lines is a weakening of the center of the line due to a narrow separation of the transverse component, throwing the light into maxima at each side. The transverse effect becomes weaker as the direction of the light becomes more nearly parallel to that of the lines of force, giving a more distinct separation of the components of the doublet. This dependence of the relative intensity of the components upon the angle of the field is unfavorable to quantitative relations between the measured separations of spark and spot lines. It is quite probable that some lines are produced more strongly than others in certain parts of the spot, on account of differences in temperature and in other physical conditions. This

would involve a difference in field strength and also of the angle to the lines of force at which the light comes to us, opening the way for many differences in the appearance of the lines in the spot and in the laboratory sources. For example, light coming almost parallel to the force lines of the solar magnetic field would give a strong preponderance of circularly polarized light. Another part of the spot, still in the field of view projected on the slit, but differing either in location or in level or both, and therefore in a different part of the solar magnetic field, might send light at a larger angle to the lines of force, giving to some extent the transverse effect and producing the central line of the triplets. This may seem to require somewhat artificial conditions, but a structure of the spot allowing for this would appear necessary to account for the relative intensity (about $\frac{3}{2}$ to 1) of the middle and side components of spot triplets such as $\lambda\lambda$ 6173 and 6302. This would require a mixture of the longitudinal and transverse effect corresponding to an angle not yet determined exactly, but greater than 30° to the lines of force and much less than 90°.

Many of these doubtful points will, it is hoped, be cleared up as the investigation is extended with improved facilities.

MOUNT WILSON SOLAR OBSERVATORY
December 5, 1908

THE SPECTRUM OF COMET *c* 1908 (MOREHOUSE)

By W. W. CAMPBELL and SEBASTIAN ALBRECHT

The one-prism spectrograph described in Bulletin No. 8 and illustrated in Bulletin No. 62, attached to the 36-inch refractor, was used in observing the spectrum of Comet *c* 1908 (Morehouse).

1908, October 20. Campbell, observer. Although the tail of the comet was easily visible to the naked eye, for at least 3° from the head, the intrinsic brilliancy of all parts was surprisingly low. The image of the head formed by the long-focus telescope was scarcely visible on the reflecting slit-plates of the spectrograph. The feeble nucleus was just visible after the eye had remained in total darkness for several minutes, and could not be used in guiding when the slit was wide enough to give promise of a successful spectrogram.

Visual observations were made with the slit 0.04 inch (1 mm) wide. It was noticed at once that the spectrum had unusual features. The carbon bands whose edges are at λ 4737, λ 5165, and λ 5635 were present in their usual relative intensities. In addition, two bands not hitherto observed at Mount Hamilton in any comet were visible on the more refrangible side of λ 4737. These were probably composed of the two pairs of lines photographed later at λ 4550–70 and λ 4255–76. There appeared to be a slight brightening in the feeble continuous spectrum near $H\beta$. Another band was thought to be visible, far up in the violet, perhaps composed of the lines photographed later at λ 4002 and λ 4022.

A photographic exposure of three hours was made, using the same slit-width. It was necessary to guide with the finding telescope, and no doubt the guiding was inefficient. The spectrogram shows five bright bands just on the limit of vision; so faint, in fact, that they become invisible under the lowest magnification.

1908, Nov. 27, 28, 29. Albrecht, observer. Visual observations were made each evening before beginning the photographs referred to below. The sky was bright with moonlight and twilight. The three usual bands at λ 4737, λ 5165, and λ 5635 were seen. Their positions were estimated closely by means of the iron spectrum, which

was thrown into view frequently, and with which the observer is familiar. The green carbon band was much stronger than the blue band, and the blue band was stronger than the yellow band. In addition, a fourth band, quite faint, was visible at a considerable distance to the violet of λ 4737. It was probably the pair at λ 4255–76.

On November 27 a spectrogram was obtained with slit-width of 0.02 inch (0.5 mm) and exposure-time of 75 minutes. The comet spectrum, containing several fairly strong lines or bands, was unfamiliar in appearance. The hydrogen comparison spectrum, underexposed, is visible on only one side of the comet spectrum. As the plate could not, therefore, be accurately oriented on the measuring microscope, a constant correction has been applied to all the micrometer readings to reduce to the same system as for the spectrogram obtained on November 28.

On November 28 the slit-width was 0.008 inch (0.2 mm) and the exposure-time 83 minutes. The recorded spectrum is much fainter than that of November 27, but the comparison spectra are excellent.

On November 29 a 90-minute exposure was made on a plate stained for sensitiveness in the red end of the spectrum. The sky was hazy, and during a part of the exposure thinly clouded. A trace of the band at λ 5165 shows on the plate. The strongest pair of lines recorded on the two earlier spectrograms at λ 4255–76, is easily visible on this plate.

The results of Albrecht's measures of the first two photographs are contained in the table. The brightest line is assigned intensity 10, and a line just visible intensity 0.

It is of interest to note the relative weakness of the edge of the first fluting in the fourth carbon band in the comet, at λ 4737. The band observed in the comet at λ 4690 is probably a blend of the third, fourth, and fifth fluting-edges. The lines at λ 3882 and λ 3869 are doubtless the first and second edges in the third cyanogen band. There is doubt whether the first cyanogen band[1] is represented in the comet, although the presence of two lines certainly and three others possibly within the limits of the band is a point in favor of their cyanogen origin. Attention should be called to the apparent entire absence of the second cyanogen band. We are unable to suggest a probable origin for the

[1] *Astronomy and Astrophysics*, **13**, 205, 1894.

TABLE I

BRIGHT LINES PHOTOGRAPHED

1908 Nov. 27 Slit-Width 0.020 in.	Nov. 28 0.008 in.	Nov. 29 0.012 in.	Mean	Relative Intensities	Carbon and Cyanogen Spectra
3836±	.....	....	384–	1	
3869	.....	....	3869	1	3871.5, 2d edge, 3d Cyanogen Band
3882.8	3881.4	....	3882.1	2	3883.6, 1st edge, 3d Cyanogen Band
3913	3915	....	3914	2	
4002.8	4002.2	....	4002.5	6	
4023.0	4021.3	....	4022.2	8	
4255.1	4254.7	4255	4254.9	8	
4276.1	4275.1	4276	4275.6	10	
452–?	453–?	....	452–?	..	4502, 4515, 4532
4548.8	4550.0	....	4549.4	4	4553 } 1st Cyanogen Band?
4571.2	4569.3	....	4570.2	3	4578 }
4598?	.....	....	460–?	..	4606
4611?	.....	....	461–?	..	
4688.2	4692.2	....	4690.2	7	4677. , 5th edge, 4th Carbon Band; 4684.9, 4th edge, 4th Carbon Band; 4697.6, 3d edge, 4th Carbon Band
4714.7	4715.1	....	4714.9	5	4715.3, 2d edge, 4th Carbon Band
4737	4738	....	4738	0	4737.2, 1st edge, 4th Carbon Band
.....	.....	516–	516–	..	5165.3, 3d Carbon Band

BANDS OBSERVED VISUALLY

4002–22± (?) Position not determined visually.
4255–76± Position not determined visually.
4550–70± Position not determined visually.
4737± Carbon—Position estimated, not accurately measured.
5165± Carbon—Position estimated, not accurately measured.
5635± Carbon—Position estimated, not accurately measured.

strong lines at λ 3913, λ 4002, λ 4022, λ 4255, λ 4276, λ 4549, and λ 4570. The last six of these lines are no doubt identical with three pairs of lines observed by Chrétien[1] in the spectrum of Comet *d* 1907, and with three bands observed in the same comet by Deslandres[2] and Evershed,[3] all using objective-prism spectrographs. Radiations having these wave-lengths seem to be relatively strong in the tails of comets, as it is difficult otherwise to account for their essential absence from the spectra of the heads of Comet *d* 1907 and other comets, as observed with slit-spectrographs.

[1] *Comptes Rendus*, **145**, 549, 1907.

[2] *Ibid*, **145**, 445, 1907. [3] *Monthly Notices*, **68**, 16, 1907.

The existence of these pairs of lines, with the lines in the pairs separated by about the same intervals, is strongly suggestive of closely related origins. The most promising hypothesis as to their origin seems to us to be that they are related to each other in much the same way as the well-known carbon bands or cyanogen bands are related. Are these six lines the edges of flutings in three bands of some element or compound, not yet observed in the laboratory?

The photographic intensity of the comet's light as compared with its visual brightness has been surprisingly great. The unusual weakness of the continuous spectrum and the presence of the three pairs of relatively strong bright lines in the blue and violet regions, which were observed as very faint lines or not at all in previous comets, no doubt supply the greater part of the explanation. We consider that the presence of these unusually strong lines more than balances the apparent relative weakness of the cyanogen band at λ 3884–72.

Reflected sunlight seems to contribute in very small measure to the comet's brilliancy.

LICK OBSERVATORY
December 10, 1908

Reviews

Populäre Astrophysik. By JULIUS SCHEINER. Leipzig and Berlin: B. G. Teubner, 1908. Pp. 706 with 30 plates and 210 figures in the text. Bound. M. 12.

The field for popular works on astronomy for general and serious readers is very well supplied with numerous and valuable books, but no work of similar merit and equal scope has been available for the reader in astrophysics. Miss Clerke's *Problems in Astrophysics* and Professor Hale's *The Study of Stellar Evolution*, excellent and inspiring though they are, do not, and were not designed to cover the whole of the rapidly developing field of astrophysics. The want is supplied, however, in the present volume; and who could be better equipped to prepare the volume than the author, an active and clever investigator in astrophysics, also well known for his standard works, *Die Spectralanalyse der Gestirne, Photographie der Gestirne, Strahlung und Temperatur der Sonne*, etc.?

Those students of the University of Berlin in the year 1906 who heard Professor Scheiner's courses entitled *Einleitung in die Astrophysik* will recognize in the present volume an elaboration of those lectures. The lectures were divided into two great parts. The first of these, dealing with instrumental equipment and methods of observation, considered the fundamental physical and physiological conceptions, spectrum analysis, photometry, solar radiation, and celestial photography. The second part gave the results of astrophysical investigations, reviewing in turn the sun, the planets, the moon, comets, meteors, zodiacal light, nebulae, and the fixed stars. The published work, which is thoroughly comprehensive, exceedingly well balanced, and straightforward in style, follows the same general scheme.

One or two errata may be noted. In the lists of lines of the chromospheric spectrum on pp. 370 and 395 the strontium line at 4078 is attributed to calcium, perpetuating an old error. Another legacy of error is found on p. 365, where the diurnal motions of solar rotation from Dunér's spectroscopic observations are given uncorrected for the motion of the earth. That these motions are synodic and not sidereal was pointed out by Dunér in the *Astronomische Nachrichten*, **167**, 167, 1905.

Recent and complete as this volume is, astrophysical research is already

making advances beyond its contents. One instance will illustrate. We read on p. 148 that until now the Zeeman effect has found no direct application in astrophysical problems, but, he continues clearsightedly, we must not conclude that it may not be of greatest moment here. And now Hale detects the Zeeman effect in the radiation of sun-spots, proving thereby the presence of a magnetic field about them.

The illustrations in the text are well selected. The plates assembled at the end of the volume illustrate a wide range of results of celestial photography, and are for the most part of very good quality. Certain of the plates have suffered in the reproduction, principal among them being the photoheliogram by Lohse, Plate I, which appears much distorted, the solar corona by Schorr, Plate IX, loses its details, and the comet photographs from the Lick Observatory, Plates XV and XVI, for which the contrast is too great. Plate X, the photograph of the solar corona by Barnard and Ritchey, is erroneously accredited to Frost.

The subject-index is unusually complete, but it is to be regretted that no author-index is added to the volume. The insufficient opacity of the paper is objectionable. Readers, other than Germans, will deplore the use of German text in the printing. This may be an additional incentive to the desired translation of the work into English.

This volume admirably fills a vacancy in popular scientific literature and makes a fitting companion to Vogel's *Newcomb-Englemann's Populäre Astronomie* and will probably be seen beside this work on the bookshelves of working astronomers and scientific readers generally.

P. F.

Die Milchstrasse. Von MAX WOLF. Leipzig: J. A. Barth, 1908. 8vo., pp. 48. Figs. 50. M. 4.

This is the issue in book form of a public lecture by Professor Wolf, illustrated with quite a number of photographs of the star clouds of the galaxy, made with his various telescopes, large and small. The text deals in a popular manner with the peculiarities of the Milky Way, and especially with the theories formulated by various astronomers to account for its existence and to explain what it really is. The main interest in the book, however, should center in the photographs that are contained in. it, for no matter how erroneous the various theories concerning the constitution of the Milky Way, the photographs are supposed to tell their own story, from which the student can judge for himself how well the theories fit into the actual appearance of this wonderful zone of stars. The reproductions

in this work, unfortunately, are not fair representations of Wolf's photographs of the Milky Way: they are really misleading in many cases. This, however, is due entirely to a want of judgment as to how much of the actual photograph should be used. There is always a falling-off of illumination when the field of a lens is not large enough to cover the entire plate. Outside of this circle of illumination the stars abruptly end, for no images are formed there by the lens. If, therefore, a full-sized print is made from such a negative, the area of illumination, where the light has acted, will appear as a bright region, and the cloud forms will extend, if they are large enough, to the edge of the circle of illumination, and will there abruptly terminate in blackness, as no images of the stars will reach the plate. In a case of this kind one should use only that part of the plate which is well covered by the circle of illumination, by matting out or cutting away the bad part. Figs. 3 to 10 in the present work, on pp. 13 to 16, are samples of this neglect of matting. Any one of these plates or Nos. 25 and 34 (with the reflector) gives the impression of a bright mass of stars isolated on a starless sky, while in reality they are but part of larger star areas. Taking these photographs as a guide, one would form quite an erroneous idea of the true forms of and extent of these cloud regions.

Among the illustrations are some excellent photographs of a number of the well-known nebulae, such as those of *Orion* and *Andromeda*, and also some of the spiral nebulae. They were made with the new 28-inch reflector. These pictures have doubtless suffered much in the reproduction. Figs. 25 and 34 are especially bad, from the inclusion of a portion of the plate beyond the circle of illumination. This fault will be strikingly apparent by comparing Fig. 25 with Fig. 24. It is indeed unfortunate that through a mere oversight in the presentation of these pictures without properly matting out the exterior bad portions, the reader should get an inadequate and erroneous impression of the accurate and effective work which Professor Wolf has for years been carrying on with such remarkable success with the admirable facilities he has established on the Königsstuhl.

E. E. B.

The Theory of Optical Instruments. By E. T. WHITTAKER. (Cambridge Tracts in Mathematics and Mathematical Physics, No. 7.) Cambridge University Press, 1907. Pp. 72, with diagrams. *2s. 6d.*, unbound.

This excellent little work was prepared by the Royal Astronomer for Ireland for those students of astronomy, photography, and spectroscopy

who desire "a simple theoretical account of those defects of performance of optical instruments to which the names *coma, curvature of field, astigmatism, distortion, secondary spectrum, want of resolving power*, etc., are given." The hope is also expressed that the attention of pure mathematicians may be drawn by it to some attractive theorems. The author also regards this "tract" as a suggestion toward a modification of the customary university course in geometrical optics.

Books and articles on this topic in English are few indeed, and but few translations have appeared of the numerous German contributions, Professor Silvanus P. Thompson's English edition of Lummer's *Beiträge zur Photographische Optik* excepted. This tract compresses in its small space the essentials of the subjects treated, and should be of wide service.

F.

The Moon in Modern Astronomy. By PHILIP FAUTH. London: A. Owen & Co. Bound, 10*s*.

This book is a summary of twenty years' work on the moon. The first sixty pages are taken up with an introduction by J. E. Gore, a historical survey by the author, in which he mildly reproves American astronomers for their neglect of visual selenography; and with a criticism of the results obtained by photography. The remaining one hundred pages discuss the subject proper. Some of the interesting points brought out are: the relation of crater depth to crater diameter, similarity of crater rings and plains, the bleaching of the surface, the lunar rays. Herr Fauth closes by stating that the moon has a thick coat of ice and supports his statement at length. The maps are excellent, showing a wonderful amount of painstaking work, but the detail which is shown is almost incredible when we find that the author has had only a 7½-inch refractor at his command. Herr Fauth explains that this is due to the character and training of his eye. The book is carefully prepared and is well worth consideration.

H. E. BUCHANAN

Two New Worlds. By E. E. FOURNIER D'ALBE. London: Longmans, Green & Co., 1907. Pp. 157.

Ingenious and well composed as this book, "written in Ireland and largely inspired by Irish thoughts and thinkers," is, we are sorry to say that from a scientific standpoint it is best described as an Irish bull. We regret this the more as the theme was grand and if scientifically accurate the book

might have given us at least an imaginative glimpse of value into the beyond. In justification of our phrase, meant in all kindliness, we will explain why the book courts the appellative, being ostensibly one thing and in reality another. The claim of the work is the advancement of proof or at least strong presumption that modern science has data for the existence of two new worlds, one infinitely little, the other infinitely big, and the key to their unlocking is given by the author in the following words: "Time and space are, after all, purely relative. If, at midnight tonight, all things, including ourselves and our measuring instruments, were reduced in size 1000 times, we should be left quite unaware of any such change." The monstrosity of this statement, coming originally from the teachings of Kant but spelled now usually with a small *c*, instead of a capital *K*, fairly takes our scientific breath away. Not know it! Why, the veriest child would perceive it at once, however unversed in physics. Every sensation dependent on two dimensions, the angular magnitude of an object for instance, would be altered in one ratio, while those dependent on three, weight for example, would be altered in another and even a baby on tumbling to the floor would wonder why he hurt himself less than yesterday—on that floor seemingly as far off as ever.

Starting with this fallacy it is not surprising that he reaches the to him remarkable premise and really startling conclusion that: "Hence in the infra-world *space and time are reduced in the same proportion.*" It is this curious circumstance which justifies the expression "infra-world." The curious circumstance is simply that distance, which he here calls space (p. 210), and time are both of one dimension and that he takes the earth's distance from the sun and not for instance *Neptune's* as the basis of comparison with atoms and electrons.

As he thus sums up his idea, nothing further in exposing its erroneousness need be said, except that it is a pity that he did not look a little more carefully before leaping onto his worlds and asking others to follow; for to persons untrained in, or averse to, mathematics such works do incalculable harm by leading them to believe that to be founded on figures which really founders on fact. P. L.

The World Machine: The Cosmic Mechanism. By CARL SNYDER. London: Longmans, Green & Co., 1907. Pp. 488. $2.50 net.

This is a popular book, the first part of a rather ambitious undertaking to record and philosophize on the universe and its contents, which is to include *The Mechanism of Life*, and *The Social Mechanism*. This part

deals almost entirely with astronomy, and is written in a sketchy, vivid style which is likely to compel the attention of the reader, though at times it becomes almost flippant in its effort to be up to date. The author has evidently read widely, though generally not at first hand, and he gives on the whole a pretty accurate as well as interesting picture of what is known and surmised of cosmogony. The book can be recommended to teachers for collateral reading by a class in descriptive astronomy, and to those who read magazine articles on scientific subjects. It is well printed on the light paper now often used in England, which makes its handling a pleasure. It is not clear why American publishers do not follow this excellent example.

F.

Halley's Comet. By H. H. TURNER. Oxford: The Clarendon Press, 1908. Pp. 32. 1*s.* net.

This evening discourse to the British Association at Dublin is written in the author's familiar and entertaining style. It is illustrated with excellent portraits of Halley and Newton, and by a sketch from *Punch*, and the drawing from the Bayeux Tapestry. It will be widely read by both those who had, and those who did not have, the privilege of hearing the lecture.

Annuaire pour l'an 1909. Publié par le Bureau des Longitudes. Paris: Gauthier-Villars. 16mo. Pp. 941. Fr. 1.85.

This indispensable volume makes its annual (113th) return, compressing a vast amount of scientific information into its small compass. Under the scheme of alternation now in effect, this issue gives, in addition to the usual astronomical data (244 pages), an extensive set of geographical, meteorological, and statistical tables. The tables relating to physics and chemistry appear in the even years. The data regarding variable stars are particularly full for 1909, comprising 139 pages, and the principal "Notice," by M. Bigourdan, is a valuable popular statement of our present knowledge on the same topic (116 pages). The second notice is by M. Lallemand, "Mouvements et déformations de la croûte terrestre" (57 pages).

A Short University Course in Electricity, Sound and Light. By R. A. MILLIKAN AND JOHN MILLS. Boston: Ginn & Co., 1908. Pp. 389; Figs. 258.

The authors state that "this book represents primarily an attempt to secure a satisfactory articulation of the laboratory and classroom phases

of instruction." An exposition of the principles of a physical topic is followed by directions for conducting an experiment or measurement, and an example is then added. The book is thoroughly modern, is clearly written, and well illustrated. In view of its practical importance, electricity occupies more than half of the volume, while optics receives about 100 pages. The work will be found useful for consultation by many whose work is in allied branches.

A Practical Manual of Tides and Waves. By W. H. WHEELER. London: Longmans, Green & Co., 1906. Pp. 201; Figs. 19.

This is not an "attempt to deal with the difficult subject of the tides in a scientific way," as the author states in the preface. It gives, however, besides the ordinary geometrical theory, a readable account of various observed facts, collected from many sources, about the tides in seas and rivers, and about oceanic waves caused by wind and seismic disturbances.

The Principles of Physics. By ALFRED P. GAGE, revised by ARTHUR W. GOODSPEED. Boston: Ginn & Co., 1907. Pp. 547; Figs. 420, 18×13 cm.

When the first edition of this book appeared, nearly twenty-five years ago, it constituted quite a departure from the elementary textbooks then existing in English. Excellent textbooks for instruction in physics in secondary schools and colleges are now numerous: this one has also improved with successive revisions, and it is well adapted to its purpose.

Die Luftelektrizität. Von ALBERT GOCKEL. Leipzig: S. Hirzel, 1908. Pp. 206, Figs. 28. Paper, 6 Marks; bound, 7 Marks.

A century and a half ago Franklin suspected and later proved the identity of lightning with frictional electricity. Others followed Franklin's lead in the study of the electric phenomena of the atmosphere, but the first marked improvement even in the apparatus used—the water dropper of Thomson (Kelvin)—came one hundred years later, and it is only now, after the lapse of half a century more, so slow has progress been, that the first book on atmospheric electricity alone has appeared.

In this the entire subject exclusive of thunder storms and auroras, is reviewed, but much the greater portion of the numerous papers referred to bear the dates of 1900 and later, and deal mainly with atmospheric

conductivity, with ionization, and with the distribution of radioactive substances; while the older papers are concerned principally with the sign and the potential gradient of the earth's electric field. Atmospheric electricity therefore may be regarded as a new subject for investigation, so much more numerous are the present problems in connection with it, and so different the methods of attack, from those of even ten years ago.

Something is known of the electric potential gradient near the ground, and of its changes as determined by time of day, by season, by mountain and plain, by rainfall and by passing clouds; but this knowledge is fragmentary for elevations greater than one hundred meters, and may be said not to exist for regions beyond two kilometers above the earth's surface. However, this is not now the chief problem. More important are the questions—How does the atmosphere become electrified? and how, in spite of its conductivity, is a difference of potential, often amounting to more than one hundred volts per meter, maintained between it and the earth?

To anyone who wishes a summary of our knowledge to date of atmospheric electricity, which recently has become the object of many investigations, the above book is recommended.

Doubtless many will agree with the reviewer in hoping that in future editions this book, now consisting of 206 octavo pages, will be enlarged by the inclusion of chapters on thunder storms and auroras, by a fuller discussion here and there of the theory, and certainly by the addition of an index.

The author gives July 20, 1752, as the date of Franklin's famous letter to Peter Collinson. This probably refers to his kite letter of October 1 of that year, read on December 21, to the Royal Society. An earlier letter of Franklin's,[1] also to Collinson and dated July 29, 1750, proposes the study of lightning and suggests the use of lightning protectors.

W. J. HUMPHREYS

MOUNT WEATHER, VA.

Annales de la Faculté des Sciences de Marseille. Tome XVII, Fascicule 3, 1908.

MM. Buisson and Fabry have published in this pamphlet the best map of the iron spectrum now available for spectroscopists. They were led to do this by the need of such an atlas for the ready identification of the

[1] Rotch, *Ciel et Terre*, **27**, 433.

iron lines they have used as "repères" in their determinations of wave-lengths by the interference method. Obtained with powerful apparatus and printed direct from the negatives without enlargement, the maps are very clean and the lines beautifully distinct. The scale is 1 tenth-meter = 0.76 mm, or almost exactly one-fourth that of Rowland's solar atlas. The map is printed on seven plates with four strips to the plate.

F.